

GEOCHEMISTRY AND GEOHYDROLOGY OF THE WEST DECKER AND
BIG SKY COAL-MINING AREAS, SOUTHEASTERN MONTANA

By Robert E. Davis

U.S. GEOLOGICAL SURVEY

Water-Resources Investigations Report 83-4225

Prepared in cooperation with the
U.S. BUREAU OF LAND MANAGEMENT and the
MONTANA BUREAU OF MINES AND GEOLOGY



Helena, Montana
February 1984

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CONVERSION FACTORS

Inch-pound units used in this report can be converted to the International System (SI) of units by the following conversion factors:

<u>Multiply inch-pound unit</u>	<u>By</u>	<u>To obtain SI unit</u>
acre	4,047	square meter
cubic foot per minute (ft ³ /min)	0.0004719	cubic meter per second
cubic foot per second (ft ³ /s)	0.02832	cubic meter per second
foot	0.3048	meter
foot per day (ft/d)	0.3048	meter per day
foot per mile (ft/mi)	0.1894	meter per kilometer
foot squared per day (ft ² /d)	0.09290	meter squared per day
inch	25.40	millimeter
mile	1.609	kilometer
ton, short	0.9072	megagram

Temperature in degrees Celsius (°C) can be converted to degrees Fahrenheit (°F) by the equation:

$$^{\circ}\text{F} = 9/5(^{\circ}\text{C}) + 32$$

National Geodetic Vertical Datum of 1929 (NGVD of 1929): A geodetic datum derived from a general adjustment of the first-order level nets of both the United States and Canada, formerly called mean sea level. NGVD of 1929 is referred to as sea level in this report.

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ABSTRACT

One of the potential hydrologic impacts of surface coal mining in southeastern Montana is a change in the quality of ground water. This study was conducted to document ground-water resources in the West Decker Mine and Big Sky Mine areas, to document present water quality and predict future water quality in mine spoils, and to predict the effects of mine spoils on the hydrologic systems.

In the West Decker Mine area, the principal aquifers are the Anderson-Dietz 1 coal bed, which is the bed being mined, and the mine spoils. Other coal beds, clinker, discontinuous sandstone lenses in the Tongue River Member of the Paleocene Fort Union Formation, and the Holocene alluvium also function as aquifers. Most of the interburden and overburden is relatively impermeable shale and clayey siltstone and sandstone.

Dissolved-solids concentration of water from the West Decker Mine spoils is about 2,500 milligrams per liter and from coal aquifers is about 1,400 milligrams per liter. The general degree of saturation of water from the spoils, using computer program WATEQF, denotes that the dissolved-solids concentration is near maximum. The concentration will not increase significantly, assuming that solute sources and temperature do not change. Laboratory batch-mixing experiments indicate that the dissolved-solids concentration of water in the spoils will not decrease in the near future; however, the concentration may decrease several hundred milligrams per liter if water from the spoils flows through a coal aquifer.

The effects of mine spoils at the West Decker Mine on the hydrologic system will be varied. Based on digital-model simulation, water levels west of the mine at post-mining equilibrium may be almost 12 feet higher than pre-mining levels. The average velocity of water moving through the spoils is estimated to be 3 feet per day, based on an effective porosity for the spoils of 0.4 percent determined from injection-withdrawal tracer tests. Ground-water discharge from the spoils will be about 0.065 cubic foot per second. About 13 years will be required for ground water moving at an average velocity of 2 feet per day to flow from the spoils to the Tongue River Reservoir. The increase in dissolved-solids load to the reservoir due to mining will be less than 1 percent.

In the Big Sky Mine area, the principal aquifers are the Rosebud and the underlying McKay coal beds of the Tongue River Member, which are both being mined, and the mine spoils. Clinker and sandy material in the Tongue River Member and alluvium along Rosebud Creek also function as aquifers. Most of the interburden and overburden is relatively permeable sandstone and relatively impermeable shale and siltstone.

Dissolved-solids concentration of water from the Big Sky Mine spoils is about 3,700 milligrams per liter and from coal aquifers is about 2,700 milligrams per liter. The general degree of saturation of water from the spoils, using computer program WATEQF, denotes that the dissolved-solids concentration is near maximum. The concentration will not increase significantly, assuming that solute sources and temperature do not change. Laboratory batch-mixing experiments indicate that the dissolved-solids concentration of water in the spoils probably will not decrease in the near future; however, the concentration may decrease several hundred milligrams per liter if water from the spoils flows through a coal aquifer.

The post-mining equilibrium flow system near the Big Sky Mine will closely resemble the pre-mining system. The average velocity of water moving through the spoils is estimated to be 1.2 feet per day, based on an effective porosity for the spoils of 8.0 percent determined from injection-withdrawal tracer tests. Ground-water discharge from the spoils to Rosebud Creek will be about 1.0 cubic foot per second. About 36 to 60 years will be required for ground water moving at an average velocity of 1.2 feet per day to flow from the spoils to Rosebud Creek. The average annual increase in dissolved-solids load to the creek due to mining will be about 2 percent.

INTRODUCTION

Coal-mining activities in southeastern Montana continue to increase in response to national energy needs. The major near-surface coal beds, which occur in the Tongue River Member of the Paleocene Fort Union Formation, are the object of the mining activities. The coal beds have a combined thickness of 80 feet in parts of the study areas and are major aquifers for domestic and livestock water supplies. Although mining of the coal beds eliminates the aquifers, replacement with the disturbed overburden, or mine spoils, creates a new aquifer.

Purpose and scope

One of the potential hydrologic impacts of surface coal mining is a change in the quality of ground water associated with replacement of coal-bed aquifers by saturated mine spoils. Therefore, this study was conducted to: (1) Document ground-water resources in the West Decker Mine and Big Sky Mine areas (fig. 1), (2) document present water quality and predict future water quality in mine spoils, and (3) predict the effects of mine spoils on the hydrologic systems.

Existing hydraulic data were used. In addition, the effective porosities of the coal aquifers and the mine-spoils aquifers were determined from four tracer tests. The nature of the post-mining equilibrium-flow system in the West Decker Mine area was predicted using a two-dimensional finite-difference flow model. The quality of water in the coal aquifers and in the mine spoils was determined from chemical analyses. Equilibrium relationships in water were determined using the computer program WATEQF. The future quality of water in the spoils and the quality of water moving from the spoils to the surrounding aquifers were predicted from batch-mixing experiments.

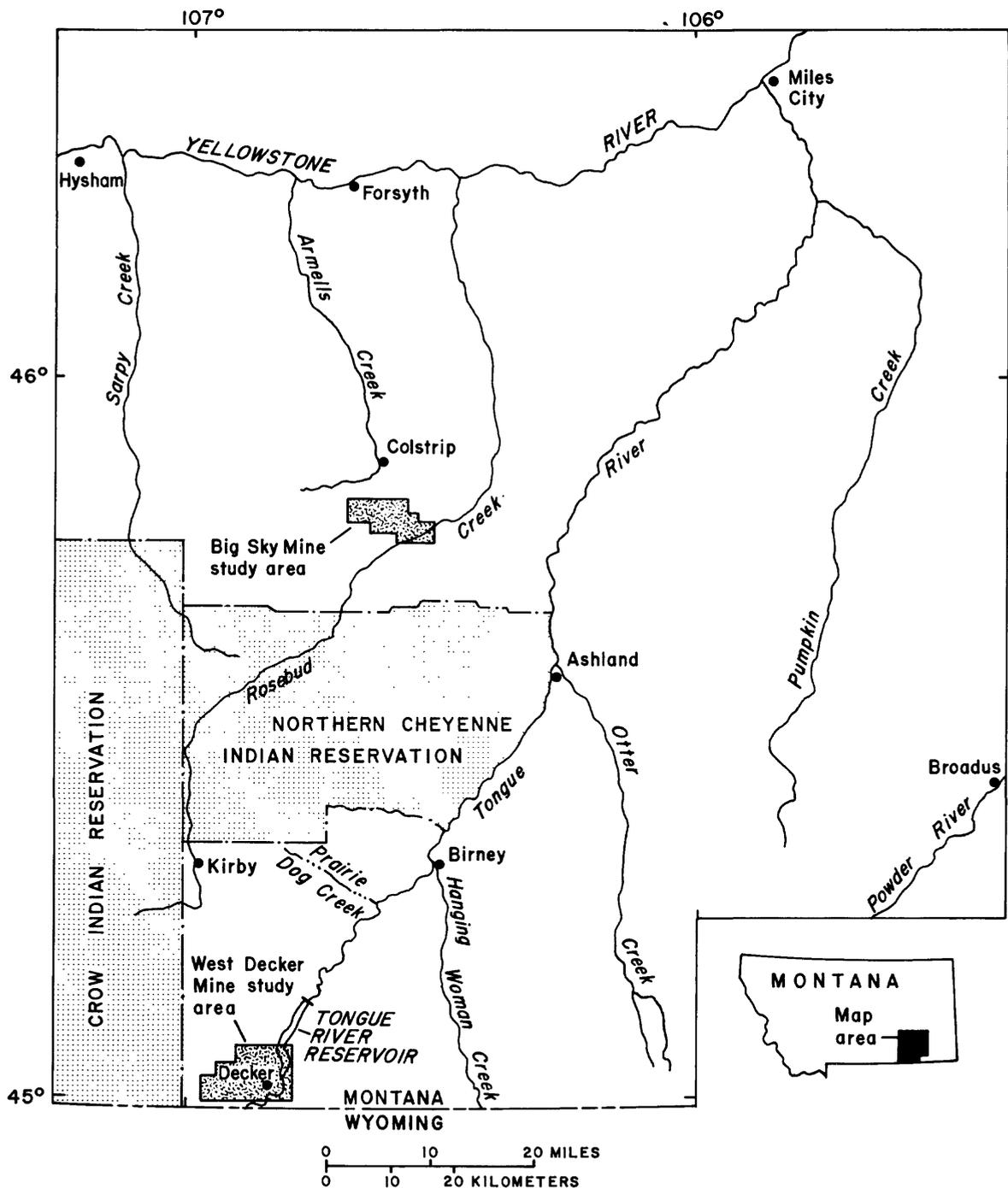


Figure 1.--Location of study areas.

Previous studies

Most of the geohydrologic data used in this report were obtained by the Montana Bureau of Mines and Geology and have been published previously in reports of Van Voast (1974), Van Voast and Hedges (1975), and Van Voast and others (1977, 1978). The regional geochemistry has been studied by Lee (1980), by Todd Hinkley in Delk and Waldhaus (1978), and by Hounslow and others (1978). Subsurface mapping

in the West Decker Mine area was conducted by Cole and Sholes (1980). Numerous studies on reclamation, surface-water infiltration, sulfate reduction, and other hydrologically related subjects have been conducted by personnel of Montana State University. The surface geology, as shown in this report, was modified from Dobbin (1930), Bass (1932), Matson and Blumer (1973), Law and Grazis (1972), and Galyardt and Murray (1981).

Well-numbering system

In this report, locations are numbered according to geographic position within the rectangular grid system used by the U.S. Bureau of Land Management (fig. 2). The location consists of as many as 14 characters. The first three characters specify the township and its position north (N) or south (S) of the Montana Base Line. The next three characters specify the range and its position east (E) of the Montana Principal Meridian. The next two characters are the section number. The next three to four characters designate the quarter section (160-acre tract), quarter-quarter section (40-acre tract), quarter-quarter-quarter section (10-acre tract), and quarter-quarter-quarter-quarter section (2 1/2-acre tract), respectively, in which the well is located. The subdivisions of the section are designated A, B, C, and D in a counterclockwise direction, beginning in the northeast quadrant. The final two digits form a sequential number; for example, well 09S40E20BDAC01 (fig. 2) is the first well inventoried in the SW1/4 NE1/4 SE1/4 NW1/4 sec. 20, T. 9 S., R. 40 E.

Physiography and drainage

Both study areas are in southeastern Montana, within the northern Great Plains physiographic province. The West Decker study area is drained by the Tongue River, which is a tributary of the Yellowstone River. Altitudes within the West Decker study area range from about 4,000 feet above sea level near the western boundary to about 3,400 feet near the Tongue River. The Big Sky Mine area is drained by Rosebud Creek, also a tributary of the Yellowstone River. Altitudes within the Big Sky Mine study area range from about 3,600 feet above sea level near the northwestern boundary to about 3,000 feet near Rosebud Creek.

Climate

Most of southeastern Montana has a semiarid climate. Average annual precipitation calculated from data of the National Weather Service for 1960-78 was 13.53 inches at Decker, Mont., and 16.46 inches at Colstrip, Mont. (fig. 3). On the average, almost half of the annual precipitation occurs during April, May, and June (fig. 4). Potential evapotranspiration for the Prairie Dog Creek area, which is located between the West Decker and Big Sky areas, is estimated to be about 40 inches annually (Larry Cary, U.S. Geological Survey, oral commun., November 1981).

Acknowledgments

The author wishes to acknowledge the help and encouragement of the personnel of the Montana Bureau of Mines and Geology. The cooperation of residents in and near the study areas who provided access to their lands is gratefully acknowledged. The author also wishes to express appreciation to the employees of the Peabody Coal

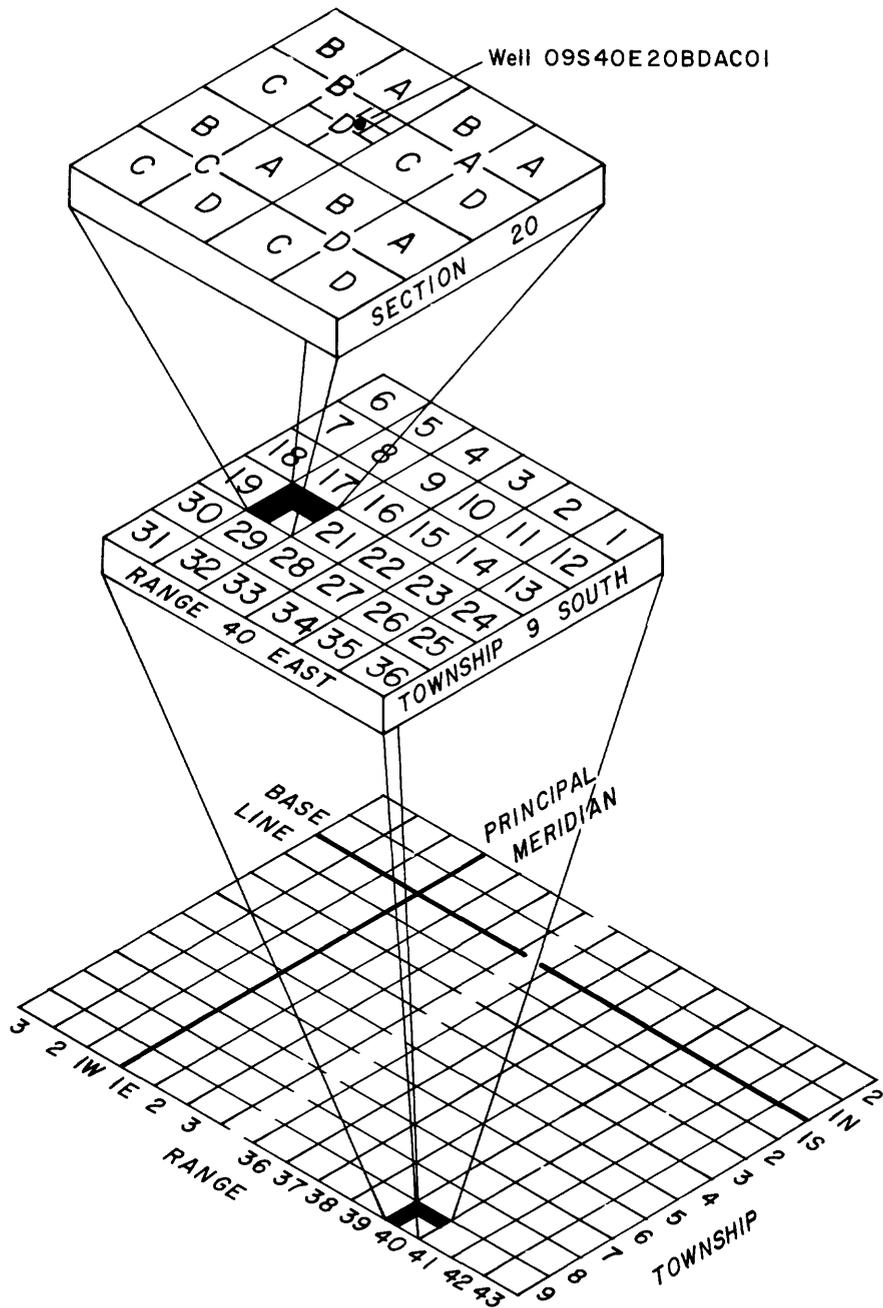


Figure 2.--Well-numbering system.

Company, Decker Coal Company, and Peter Kiewit Sons, Inc., for their help and cooperation. The personnel of Hydro-Engineering, Casper, Wyo., provided valuable input to the design of the batch-mixing experiment and apparatus. This study was conducted in cooperation with the U.S. Bureau of Land Management and the Montana Bureau of Mines and Geology.

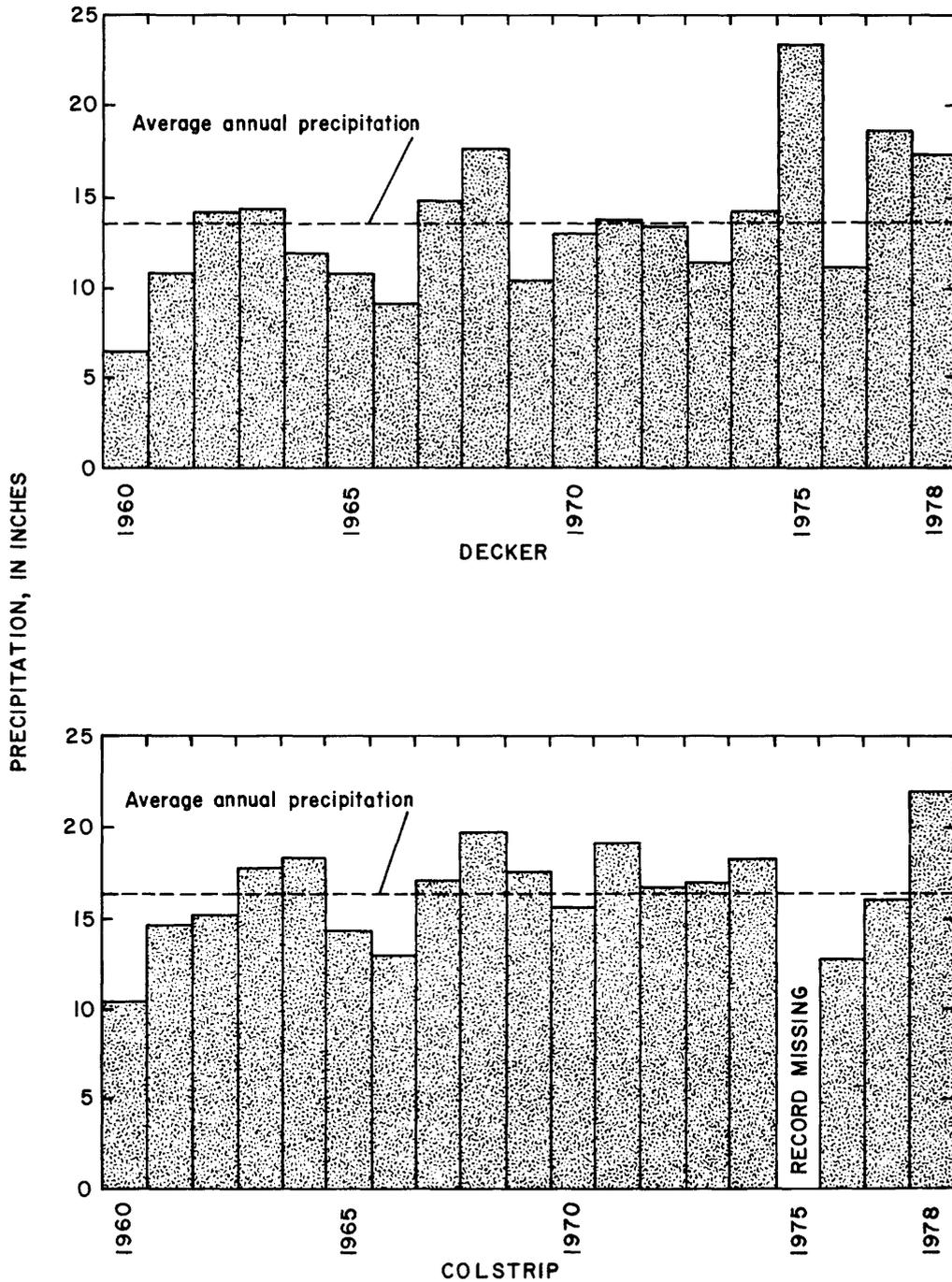


Figure 3.--Annual precipitation at Decker and Colstrip, 1960-78.

Terminology

Movement of water through the aquifers is from points of higher hydraulic head to points of lower hydraulic head. The term hydraulic head, as used in this report, means static hydraulic head. The static hydraulic head is the height above sea

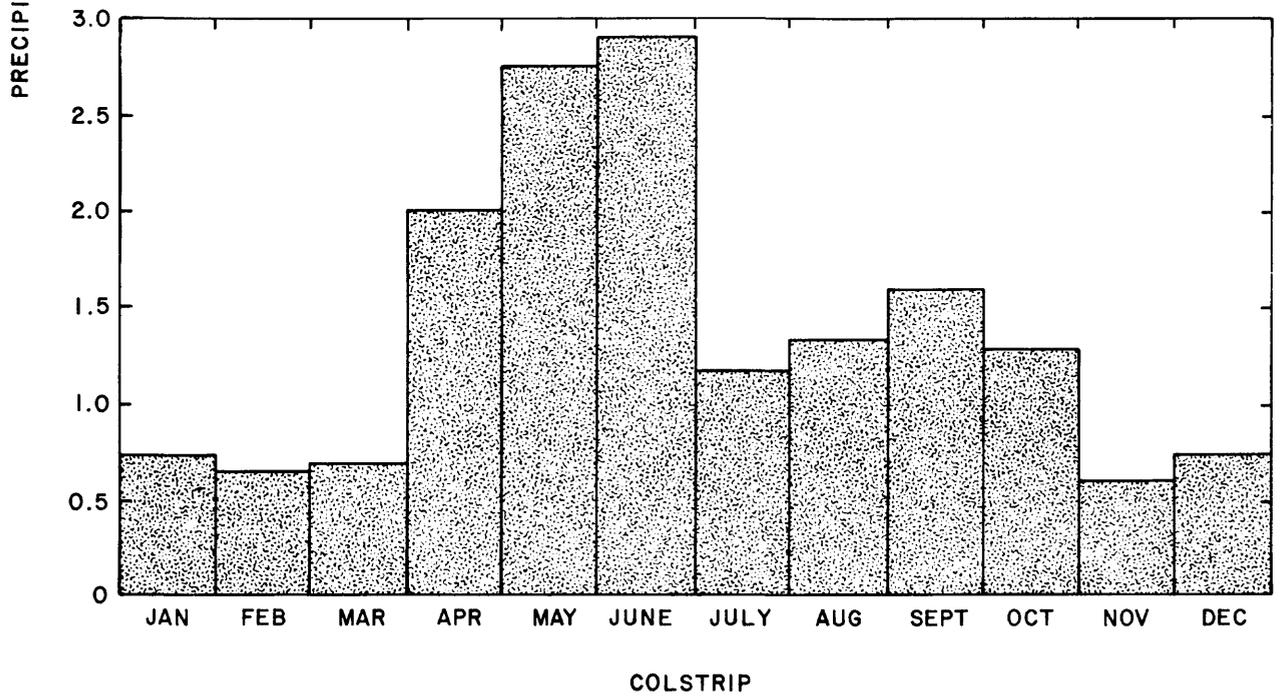
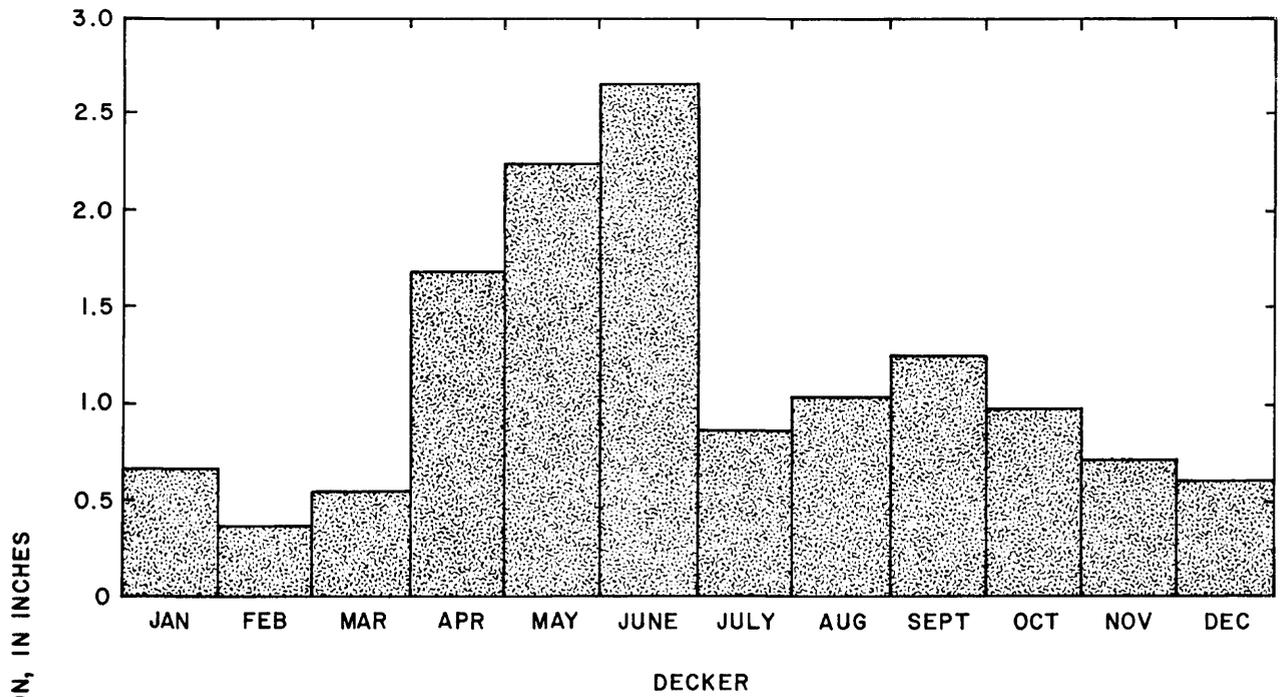


Figure 4.--Average monthly precipitation at Decker and Colstrip, 1960-78.

level of the surface of a column of water that can be supported by the static pressure at a given point (Lohman, 1972, p. 7).

The quantity of water that an aquifer can yield to wells depends upon the hydrologic properties of the aquifer. The ability of an aquifer to transmit water is measured by its transmissivity (T), which is the rate at which water of the prevailing temperature is transmitted through a unit width of the aquifer under a unit hydraulic gradient; it is expressed in units of feet squared per day (Lohman and others, 1972, p. 13).

The hydraulic conductivity (K) of an aquifer is the volume of water at the existing temperature that will move in unit time under a unit hydraulic gradient through a unit area measured at right angles to the direction of flow; it is expressed in units of feet per day (Lohman and others, 1972, p. 4). The hydraulic conductivity of an aquifer multiplied by the saturated thickness equals the transmissivity.

The effective porosity of an aquifer is the amount of interconnected pore space available for fluid transmission. Effective porosity is expressed as a percentage of the bulk volume occupied by the interconnected pore space (Lohman and others, 1972, p. 10).

METHOD OF STUDY AND EXPERIMENT DESIGN

Several techniques were used to help define the characteristics of the hydrologic systems studied. Injection-withdrawal tracer tests were conducted at four sites to determine effective porosity of the coal and the spoils aquifers. The tests were conducted by circulating water between two wells, which were spaced about 20 feet apart and hydraulically connected only to the aquifer being tested. A finite pulse of tracer, sodium bromide, was injected in one well while the other well was pumped at a constant rate. The water pumped was monitored for bromide concentration and recirculated into the injection well. The data from the tests were analyzed using a procedure described by Grove (1971). In this method, the experimental breakthrough curve for the bromide-ion concentration was compared to theoretical breakthrough curves for various values of effective porosity and dispersion constant. The breakthrough curves consist of a plot of time versus relative concentration. The relative concentration is the observed pumped bromide concentration divided by the bromide concentration in the initial injection solution. The values of effective porosity and dispersion constant that produced the theoretical curve most closely matching the experimental curve are considered to be most representative of the aquifer at the test site.

A two-dimensional finite-difference digital modeling program described by Trescott and others (1976) was used to simulate post-mining equilibrium ground-water flow in the West Decker area. Minor modifications to the program were necessary to simulate the hydrologic system.

The computer program WATEQF (Plummer and others, 1978) was used to determine equilibrium relationships in water from observation wells in the study areas. The program can determine from a water-quality analysis the degree of saturation of the water with respect to a given mineral species. The degree of saturation is expressed by the saturation index, which is the logarithm of the ratio of the ion activity product to the equilibrium constant. Positive values of the saturation index indicate supersaturation, negative values indicate undersaturation, and values near zero indicate saturation. Therefore, saturation or supersaturation with respect to a given mineral species implies the possible presence of that mineral

species in the aquifer. Undersaturation with respect to a mineral species implies that the ground water has limited contact or no contact with the mineral species. This knowledge, coupled with mineralogic data, can help in determining the hydrological and geochemical processes occurring in the hydrologic system.

Batch-mixing experiments were conducted to simulate changes in ground-water quality that may occur as a result of mining operations. Several weight-ratio combinations of water and rock material from various parts of the study areas were mixed for about 2 hours. Mixtures with coal utilized chunks of coal about 1 inch on a side. Mixtures with spoils utilized material in a generally granular form. Mixing was accomplished by affixing the mixture bottles, which were filled to exclude oxygen, to a vertical wheel that is 3 feet in diameter and rotating at three revolutions per minute. The mixtures then were allowed to settle and were filtered after a total contact time of about 24 hours. Four of the mixtures, W1F211, W1F212, W1F511, and W1F512 from the West Decker Mine area, had to be centrifuged before filtering, owing to the large amount of rock material that would not otherwise settle. The filtrate then was analyzed by the Montana Bureau of Mines and Geology.

GENERAL GEOCHEMICAL PROCESSES

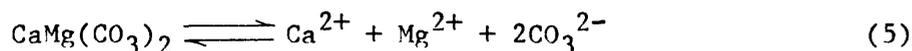
The general geochemical processes that affect the ground-water quality in southeastern Montana are as follows: water containing carbon dioxide percolates below ground surface, dissolves carbonate minerals and possibly gypsum, and exchanges calcium and magnesium ions for sodium ions. The following reactions illustrate these processes more specifically. In a near-surface environment, carbon dioxide gas (CO_2) from the atmosphere and from organic decay reacts with water (H_2O):



The resulting carbonic acid (H_2CO_3) dissociates:

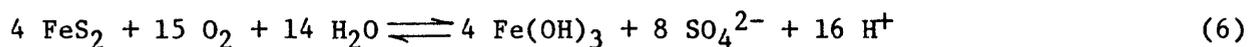


The effect of reactions 1, 2, and 3 is to produce a slightly acidic environment conducive to the dissolution of calcite (CaCO_3) and dolomite [$\text{CaMg}(\text{CO}_3)_2$]:



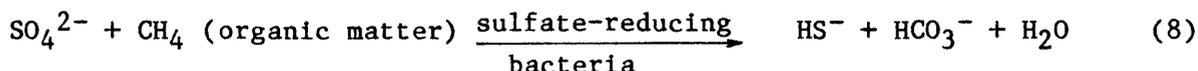
Reactions 4 and 5 result in an increase in the concentrations of calcium (Ca^{2+}) and magnesium (Mg^{2+}), and an increase in the concentration of carbonate (CO_3^{2-}), which forces a decrease in hydrogen (H^+) concentration and an increase in bicarbonate (HCO_3^-) concentration. The adsorption of calcium and magnesium ions and the release of sodium ions by exchange reactions with clay minerals and organic materials also force a decrease in hydrogen-ion concentration and an increase in bicarbonate-ion concentration. The net result of the above reactions is a moderately alkaline water containing mainly calcium, magnesium, sodium, and bicarbonate ions.

If pyrite (FeS₂) is present in the oxidizing near-surface environment, calcium sulfate (CaSO₄) may be formed. Generalized reactions for the principal processes involved are:



The sulfate ions (SO₄²⁻) produced in reaction 6 either are transported in solution to the aquifer or are precipitated as calcium sulfate near the surface as in reaction 7. The precipitated calcium sulfate may be redissolved later and transported to the aquifer by deeply percolating recharge water.

In anaerobic conditions, sulfate may be reduced to sulfide by bacteria:



Sulfate-reducing bacteria are known to be present in both study areas (Dockins and others, 1980). Therefore, depending on the hydrological, geochemical, and biological processes that predominate in an area, the ground water can be of a calcium magnesium bicarbonate, sodium bicarbonate, calcium magnesium sulfate, or sodium sulfate type.

WEST DECKER MINE AREA

Geology

The surface geology in the West Decker Mine area is predominantly the Tongue River Member of the Paleocene Fort Union Formation (fig. 5). The Tongue River Member consists of as much as 2,200 feet of tan to gray shale, siltstone, very fine to fine-grained sand and sandstone, and coal beds. The main coal beds in the West Decker Mine area are, in descending stratigraphic sequence, the Anderson, Dietz 1, Dietz 2, and Canyon. In the western part of the West Decker area, the Anderson, Dietz 1, and Dietz 2 beds are combined into one bed (Anderson-Dietz 1-Dietz 2) that is about 80 feet thick. In the eastern part of the area, the Anderson and Dietz 1 beds are combined into one bed (Anderson-Dietz 1) that is about 50 feet thick. The Anderson-Dietz 1 is separated from the 25-foot thick subjacent Dietz 2 bed by as much as 65 feet of interburden. The coal being mined at the West Decker Mine is the combined Anderson-Dietz 1 bed.

The overburden primarily consists of calcareous shale, siltstone, and very fine to fine-grained sand and sandstone. Seventy-one overburden samples obtained from five core holes in the valley of nearby Hanging Woman Creek (fig. 1) were analyzed by X-ray diffraction. The core holes penetrate the same general stratigraphic section as that in the West Decker Mine area. The samples contained primarily quartz, layer silicates, and the clay-mineral groups smectite, illite, chlorite, and kaolin (Delk and Waldhaus, 1978, p. 62-70). Also present, in general descending order of abundance, were feldspars, calcareous and dolomitic carbonates, calcium siderite and siderite, and pyrite. Gypsum was detectable in only two of the samples.

Thirty-three overburden samples from two core holes in the West Decker Mine area were analyzed by Montana State University for the Decker Coal Company. The average clay content of these samples was about 20 percent. The major clay-mineral group was determined to be smectite, with lesser amounts of illite, kaolin, and chlorite (data from Decker Coal Company). Vermiculite was present in only three of the samples. Widmayer (1977, p. 34) also reported the average silt and clay content of surface samples from the Decker area to be about 20 percent.

Clinker, which consists of fractured shale, siltstone, and sandstone that have been baked by the burning of underlying coal beds, is present within much of the study area (fig. 5). The clinker is tan to red to black and is very permeable as a result of the fracturing. The only major area of clinker that has a direct hydraulic connection with the Anderson-Dietz 1 coal bed is north of the West Decker Mine.

Isolated areas of the Eocene Wasatch Formation stratigraphically overlie the Tongue River Member in parts of the West Decker Mine study area. The Wasatch Formation is lithologically similar to the Tongue River Member.

Holocene alluvium is present along the Tongue River and its major tributaries. The alluvium consists of silt, sand, and gravel.

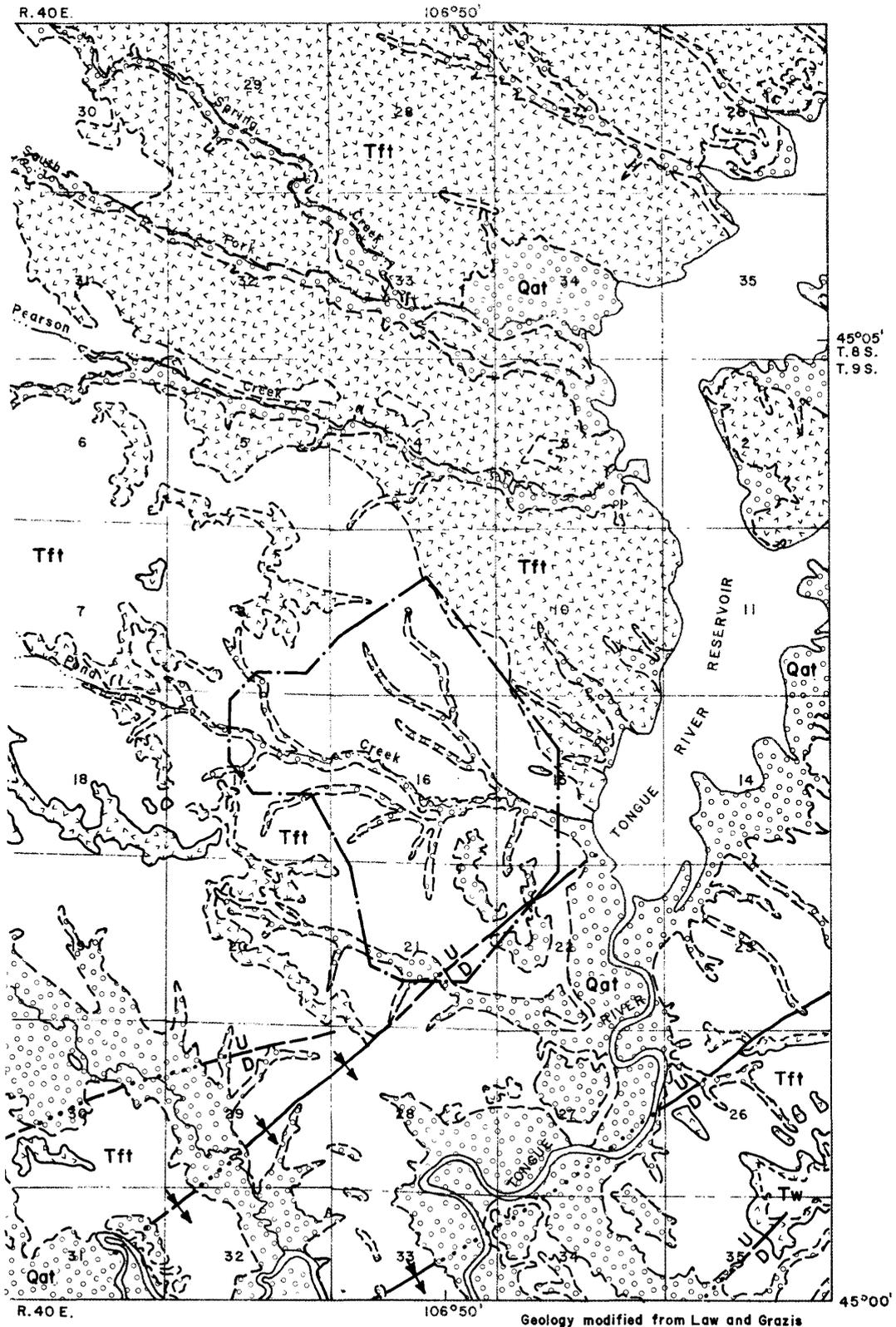
Several northeast-trending faults are present in the West Decker Mine study area (fig. 5). Vertical displacement along the faults is as much as 300 feet (Van Voast and Hedges, 1975, p. 8), with the southeast side generally being downthrown. In some areas the faults are relatively impermeable barriers to ground-water flow (Van Voast and Hedges, 1975, p. 7). In this investigation, all major faults in the West Decker Mine study area are assumed to be barriers to ground-water flow. This assumption is probably valid because faulting would juxtapose coal-bed aquifers against the relatively impermeable overburden and interburden, thus limiting horizontal ground-water flow. Also, the shales and siltstones probably inhibit vertical flow along the fault.

Geohydrology

The location of selected wells near the West Decker Mine is shown in figure 6. Data from these wells are contained in tables 1, 2, and 3. Although all the main coal beds function as aquifers, the principal coal aquifer of interest is the Anderson-Dietz 1 coal bed. The approximate altitude of the pre-mining potentiometric surface in the Anderson-Dietz 1 and connecting Anderson-Dietz 1-Dietz 2 coal aquifer near the West Decker Mine is shown in figure 7. The areas of highest hydraulic head are generally in the western and northern parts of the study area. The area of lowest hydraulic head is in the eastern part of the study area along the Tongue River Reservoir.

Another principal aquifer consists of the mine spoils, which is non-coal bearing overburden material that has been moved during surface mining. The spoils aquifer consists primarily of a rubble zone at the base of the spoils and generally is confined by relatively impermeable clay in the overlying spoils.

Clinker and alluvium also are an aquifer. The clinker and alluvium aquifer hydraulically connects aquifers in the mine area with the Tongue River Reservoir, and generally is more permeable than other aquifers in the study area.



Geology modified from Law and Grazis (1972) and Galyardt and Murray (1981).
 Boundary of mine area from Van Voast and Hedges (1975)

West Decker Mine study area.

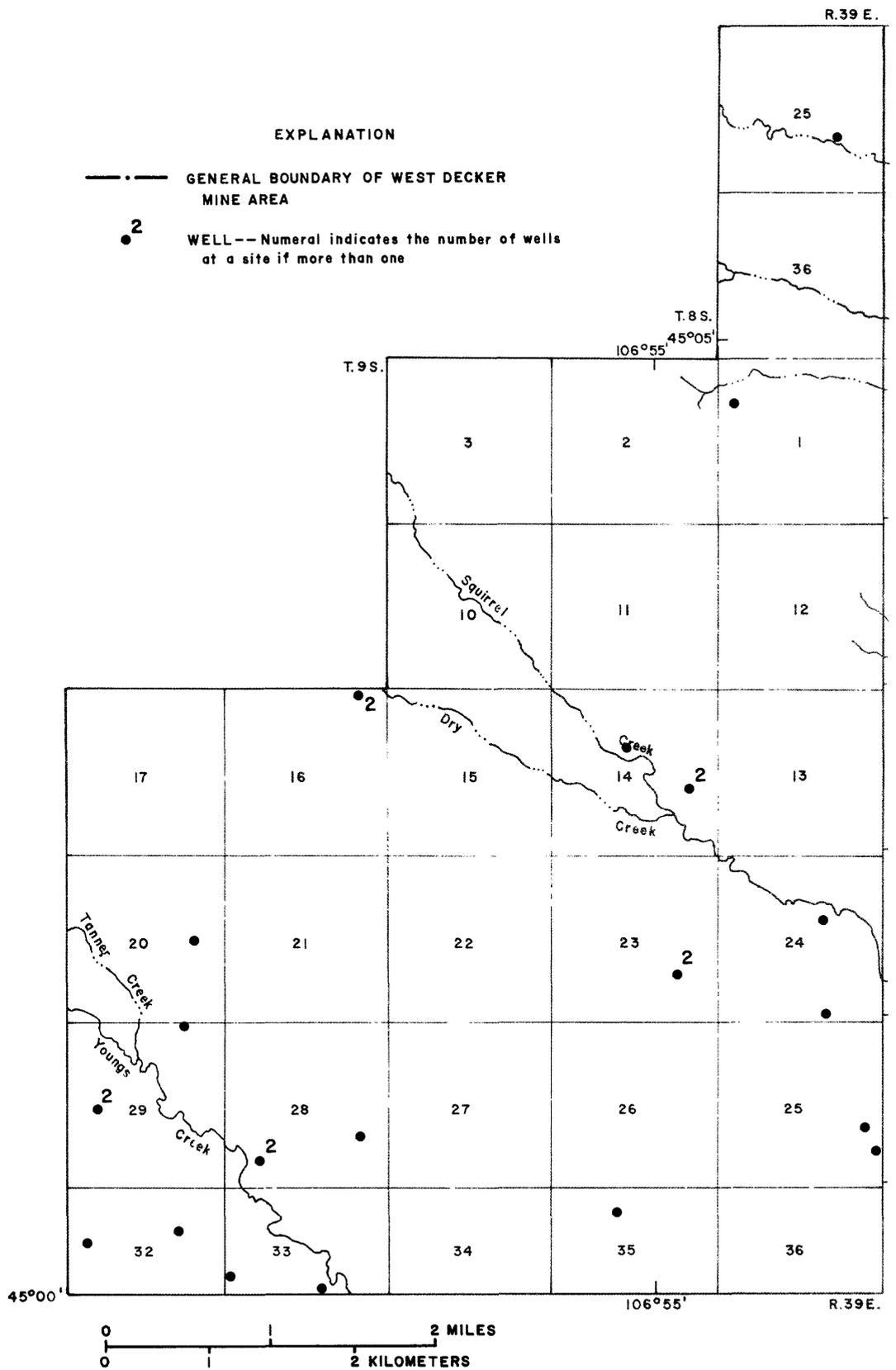
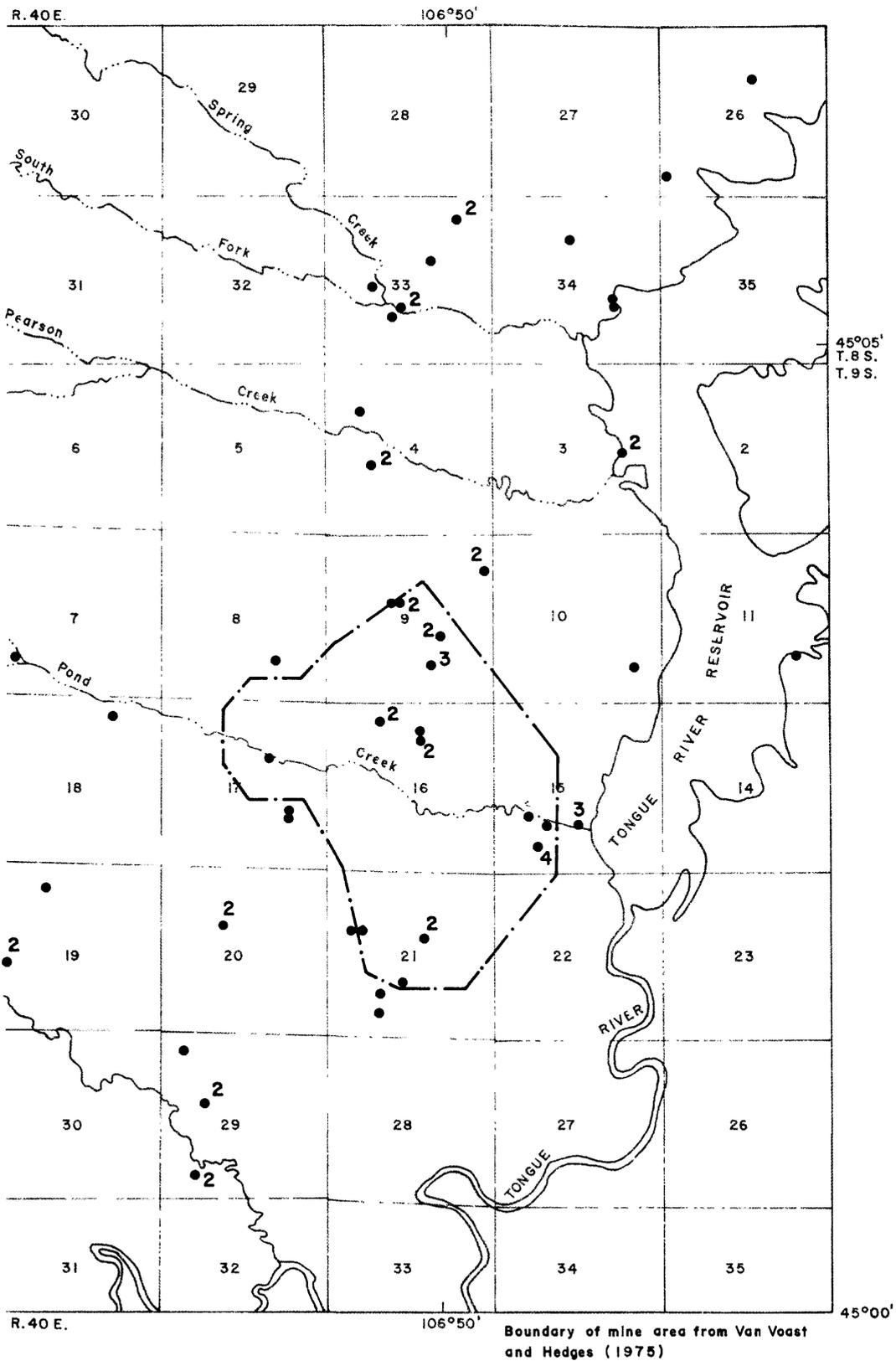


Figure 6.--Location of data-collection



sites, West Decker Mine study area.

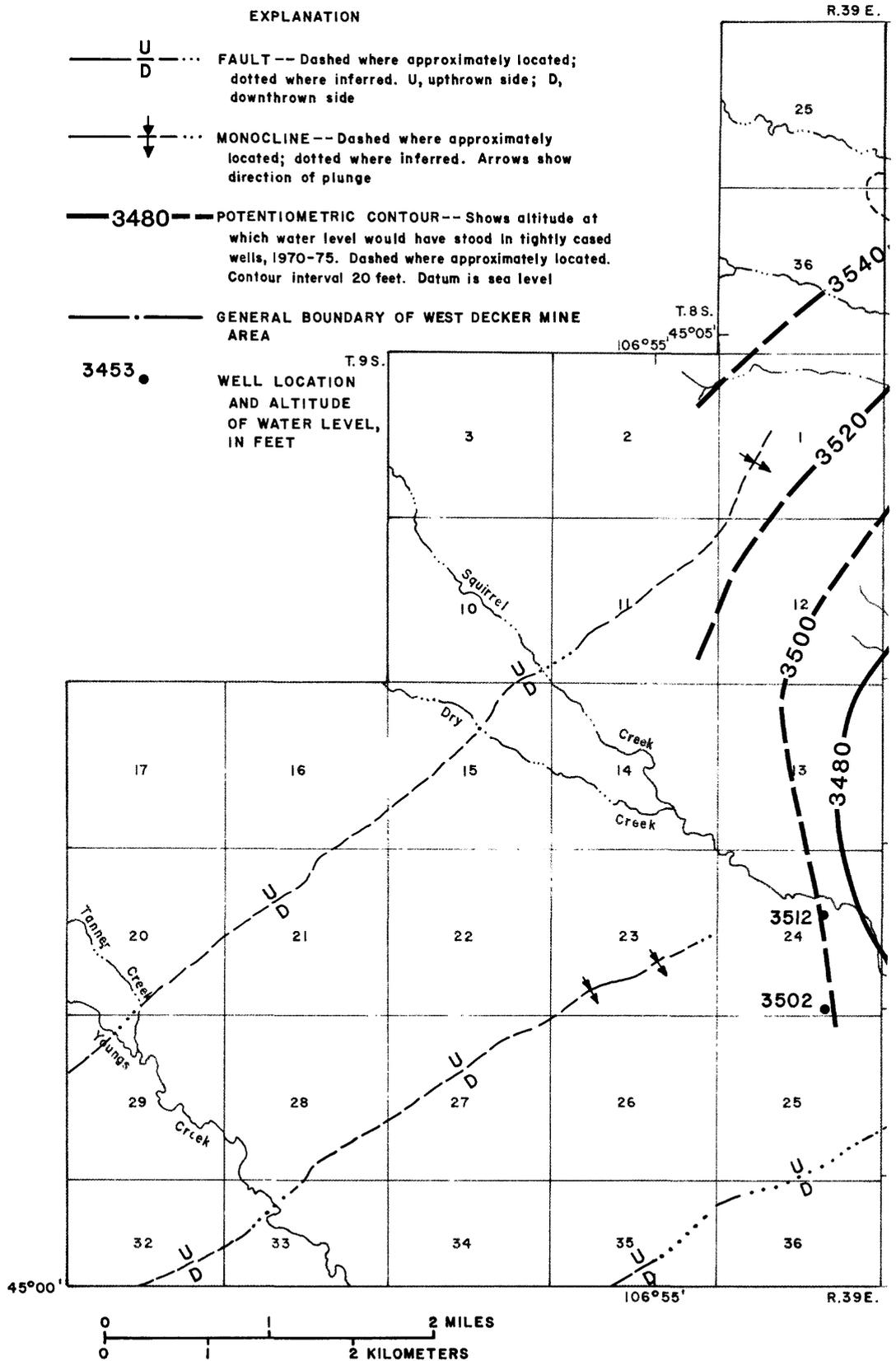
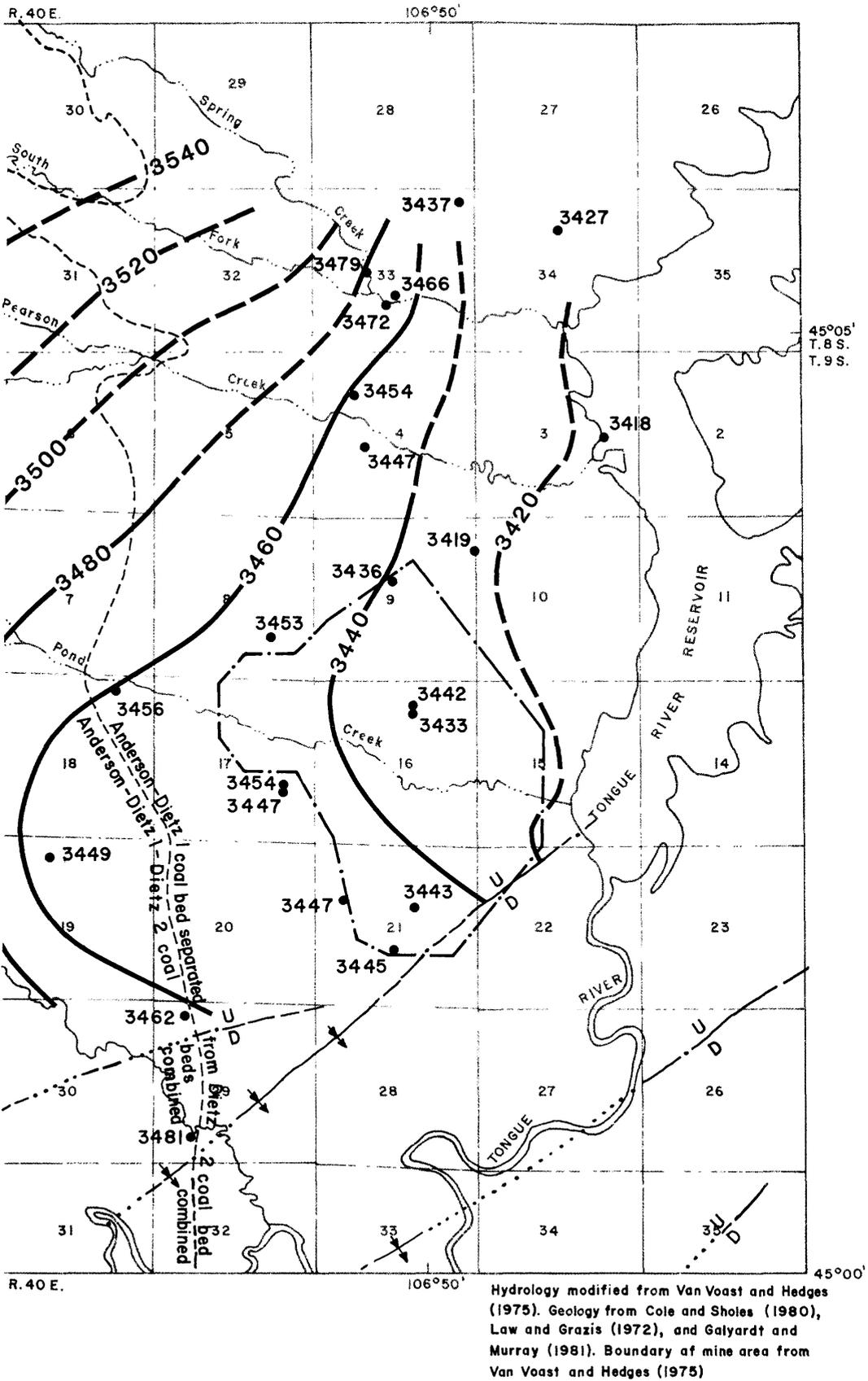


Figure 7.--Potentiometric surface of water in the Anderson-Dietz 1 and Anderson-



Dietz 1-Dietz 2 coal aquifer before mining, West Decker Mine study area.

Discontinuous sandy lenses in the Tongue River Member also contain water, but they are not areally extensive and function only as a source of small quantities of water. Most of the interburden and overburden in the study area is relatively impermeable owing to the shale and clay content.

Recharge

Recharge to the Anderson-Dietz 1 coal aquifer is by infiltration of precipitation, by upward leakage from the Dietz 2 coal bed, and by lateral flow from aquifers outside the study area. Most recharge by infiltration of precipitation probably occurs during spring snowmelt or after extended wet intervals during April, May, and June when precipitation is greatest. The infiltration probably is limited to the areas of hydraulically connected clinker and alluvium, owing to the swelling nature of the clays in the overburden. Recharge in the clinker and alluvium areas is estimated to be less than 1 inch annually. Recharge by upward leakage from the Dietz 2 coal bed occurs in the southeastern part of the West Decker Mine study area. There, the hydraulic head in the Dietz 2 is higher than the hydraulic head in the Anderson-Dietz 1.

Recharge to the spoils primarily occurs as lateral flow from the Anderson-Dietz 1 coal aquifer. Infiltration of precipitation probably is not a significant source of recharge for the spoils.

Discharge

Discharge from the Anderson-Dietz 1 aquifer exists as outflow through clinker and alluvium that is eventually received by the Tongue River Reservoir, downward leakage to the Dietz 2 coal, and pumpage from wells for domestic and stock use. The magnitude of discharge to the reservoir cannot be physically measured. However, pre-mining discharge from the general area of the West Decker Mine was calculated to be about $3.5 \text{ ft}^3/\text{s}$, most of which was from clinker north of the mine boundary (Van Voast and Hedges, 1975, p. 7). Evapotranspiration from the saturated zone occurs in the clinker and alluvium near the reservoir. Losses to evapotranspiration are not deducted from the estimate of discharge from the coal aquifers, through the alluvium, to the reservoir. The annual evapotranspiration near the reservoir probably is about the same as the potential annual evapotranspiration of 40 inches.

Leakage to the Dietz 2 coal generally occurs in the northeastern part of the study area. There, the hydraulic head in the Dietz 2 coal bed is lower than the hydraulic head in the Anderson-Dietz 1 coal.

The quantity of water pumped for domestic and stock use is small. Most wells produce water at a rate less than $1 \text{ ft}^3/\text{min}$ (Van Voast and Hedges, 1975, p. 8).

Discharge from the spoils will be through the clinker and alluvium east of the spoils and eventually to the Tongue River Reservoir. However, significant discharge probably will not occur until mining is completed.

Hydraulic conductivity and transmissivity

Aquifer tests were conducted by the Montana Bureau of Mines and Geology as parts of previous studies of aquifers in the area (Van Voast and others, 1978, p. 21 and 82). The results of 16 tests of coal aquifers indicate a range in hydraulic conductivity of 0.46 to 29 ft/d, with an average of 5.2 ft/d and a median of 2.2 ft/d. The transmissivity determined from these tests ranged from 6.5 to 440 ft²/d, with an average of 94 ft²/d and a median of 51 ft²/d. The results of six aquifer tests on the spoils aquifer indicate a range in hydraulic conductivity of 0.0033 to 8.4 ft/d, with an average of 2.8 ft/d and a median of 1.8 ft/d. Transmissivity ranged from 0.032 to 130 ft²/d, with an average of 51 ft²/d and a median of 42 ft²/d.

The hydraulic conductivity of the coal aquifers is due primarily to fractures, or cleat, in the coal. The orientations of fractures in sandstones near Decker are mainly northeast-southwest, which corresponds generally to the strike of the regional structure, and northwest-southeast, which is approximately perpendicular to the strike (Widmayer, 1977, p. 8). The fracture systems in the coals probably have similar orientations. The fractures oriented perpendicular to the strike generally are the most continuous, which results in anisotropic hydraulic conductivity (Stone and Snoeberger, 1977, and Stoner, 1981). Therefore, the direction of maximum hydraulic conductivity probably is northwest-southeast, and the direction of lesser hydraulic conductivity probably is about northeast-southwest. Stone and Snoeberger (1977, p. 437) determined the ratio of the anisotropy in a coal aquifer in northeastern Wyoming to be about 0.6 to 1. Similarly, Stoner (1981, p. 37) determined the average ratio of anisotropy for several coal aquifers in southeastern Montana to be about 0.4 to 1. The aquifer tests conducted by the Montana Bureau of Mines and Geology were not designed to determine anisotropy.

Effective porosity

Two recirculating injection-withdrawal tracer tests were conducted to determine the effective porosity of the Anderson-Dietz 1 coal bed and of the West Decker Mine spoils. The tests were conducted using wells 09S40E20BDAC01 and 09S40E20BDAC02 that were completed in the Anderson-Dietz 1 coal bed and wells 09S40E09DBAD01 and 09S40E09DBAD02 that were completed in the spoils (table 1). The following conditions were in effect during the tests:

	<u>Anderson-Dietz 1 coal</u>	<u>Mine spoils</u>
Distance between wells (feet)	19.03	19.68
Withdrawal rate (cubic feet per minute)	1.27	0.66
Injectant concentration (Molar)	0.0138	0.0422
Time of injection (minutes)	43	25
Aquifer thickness (feet)	50	11

The theoretical and observed tracer-concentration breakthrough curves are compared in figures 8 and 9. The theoretical curves were not calculated beyond the time corresponding to the beginning of the second recirculation of the tracer, owing to limitations of the analyzing program from which they were produced (Grove, 1971). For the Anderson-Dietz 1 coal aquifer, the theoretical curve produced by using an effective porosity of 0.3 percent and a dispersion constant of 1.0 foot most closely matched the observed curve (fig. 8). For the mine-spoils aquifer, the

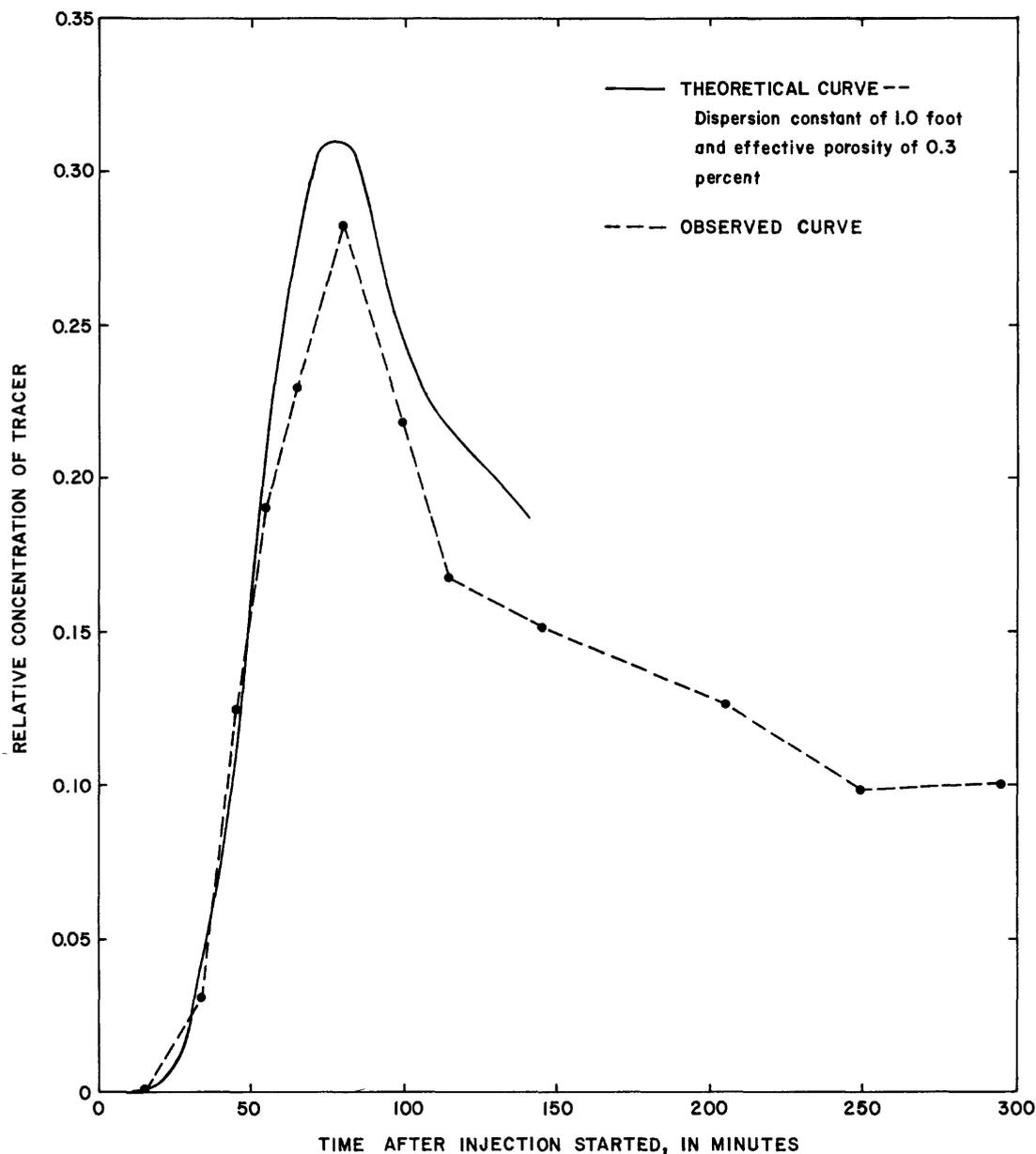


Figure 8.--Theoretical and observed breakthrough curves for injection-withdrawal tracer test, Anderson-Dietz 1 coal bed, West Decker Mine area.

theoretical curve produced by using an effective porosity of 0.4 percent and a dispersion constant of 1.0 foot most closely matched the observed curve (fig. 9).

The small values of effective porosity determined from these tests may reflect actual aquifer characteristics or may be due to experimental error. However, the values are within the range attributed to fractured media (Freeze and Cherry, 1979, p. 408). The depth of the wells used for the coal-aquifer test is 380 feet. At that depth, the size of the cleat openings may be small because of the weight of the overburden, resulting in a small effective porosity. The large clay content of the spoils also may result in a small effective porosity. For both tests, if

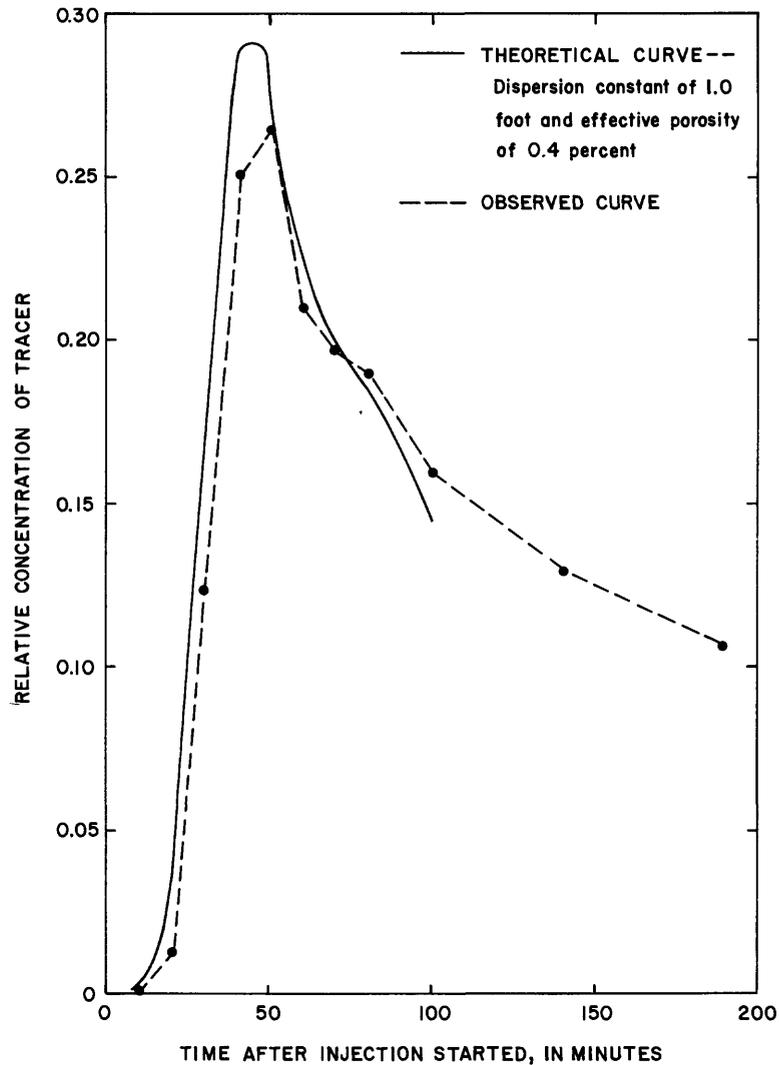


Figure 9.--Theoretical and observed breakthrough curves for injection-withdrawal tracer test, West Decker Mine spoils.

the tracer did not flow through the entire aquifer thickness but through a less-thick zone more favorable to transmission of the tracer, then the results of the experiment would indicate a smaller effective porosity than actually exists. The magnitude of the effect of this experimental error, if it is relevant, is unknown.

The sensitivity of the analyzing procedure is shown in figures 10 through 13. An increase in effective porosity decreased the magnitude of the peak of the curve, whereas a decrease in effective porosity increased the magnitude of the peak. An increase in the dispersion constant tended to move the curve to the left, and a decrease in the dispersion constant tended to move the curve to the right.

Owing to the relatively close spacing of the wells tested, the dispersion constants determined from the test analyses probably are not representative of the aquifers as a whole. Also, because only one test was conducted for each aquifer and because the area of influence of each test is only a small part of each aquifer

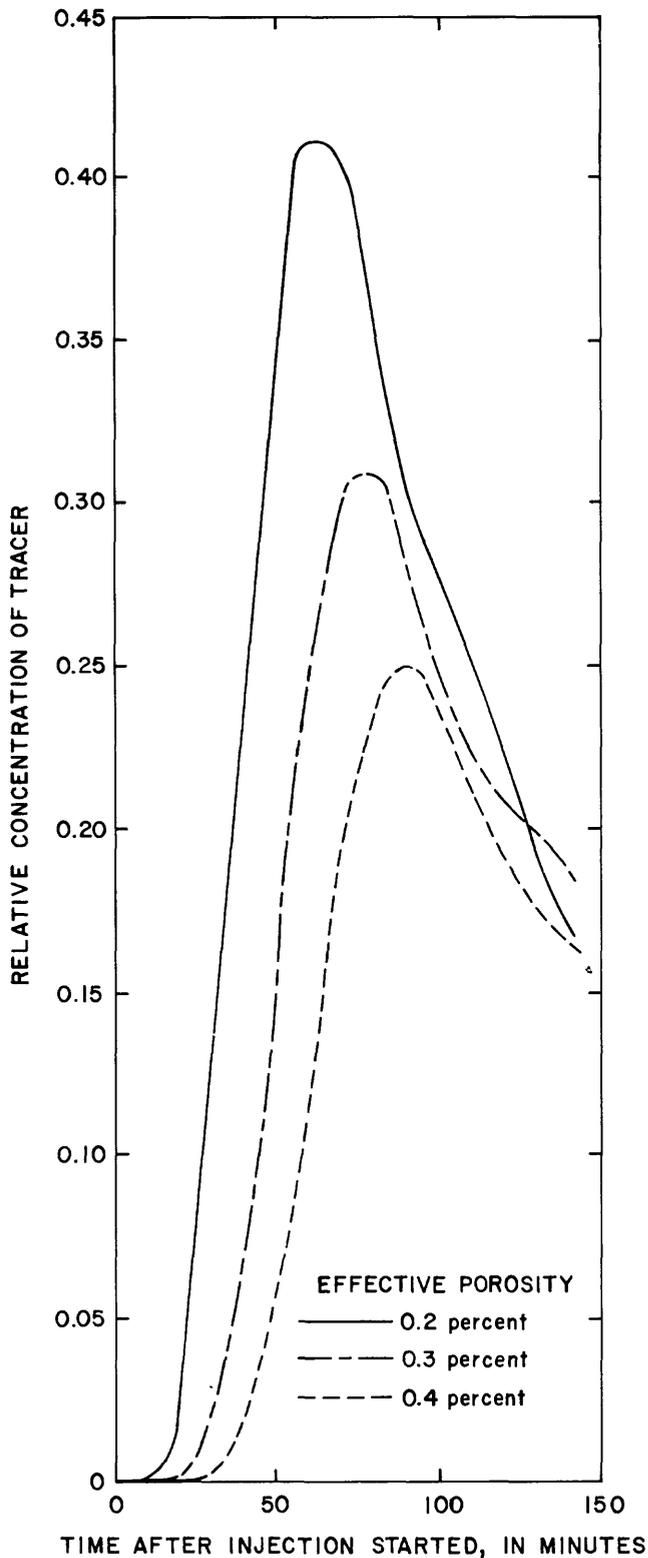


Figure 10.--Theoretical breakthrough curves for various values of effective porosity with a dispersion constant of 1 foot, Anderson-Dietz 1 coal bed, West Decker Mine area.

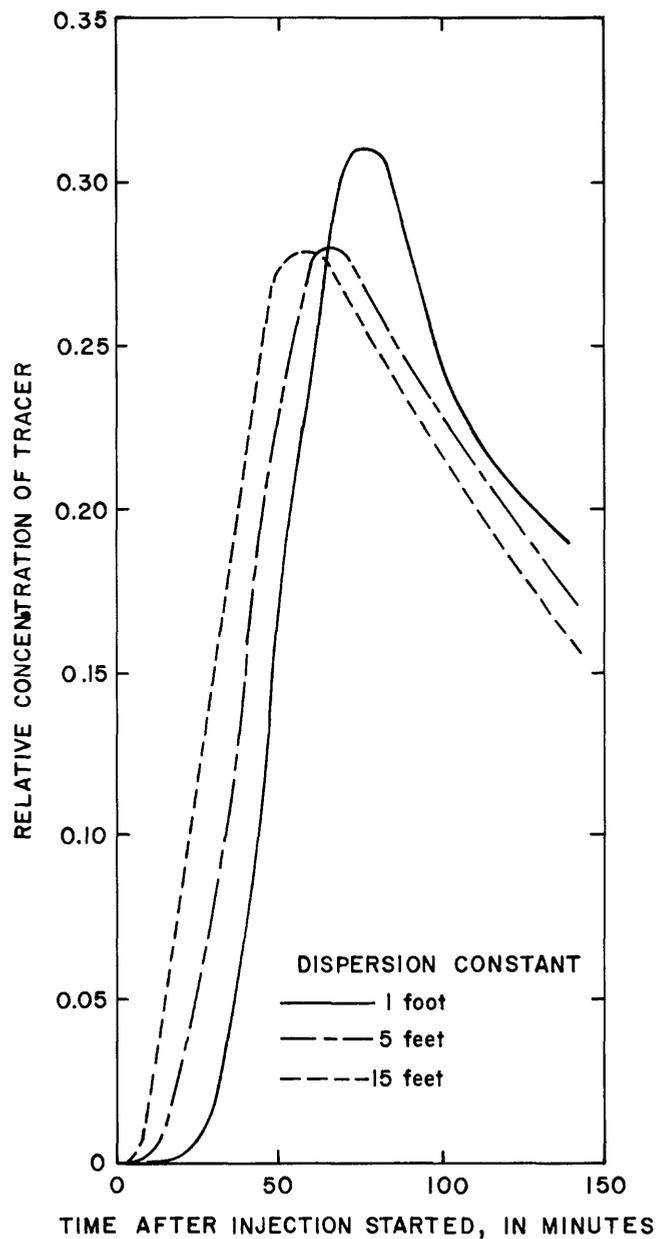


Figure 11.--Theoretical breakthrough curves for various values of dispersion constant with an effective porosity of 0.3 percent, Anderson-Dietz 1 coal bed, West Decker Mine area.

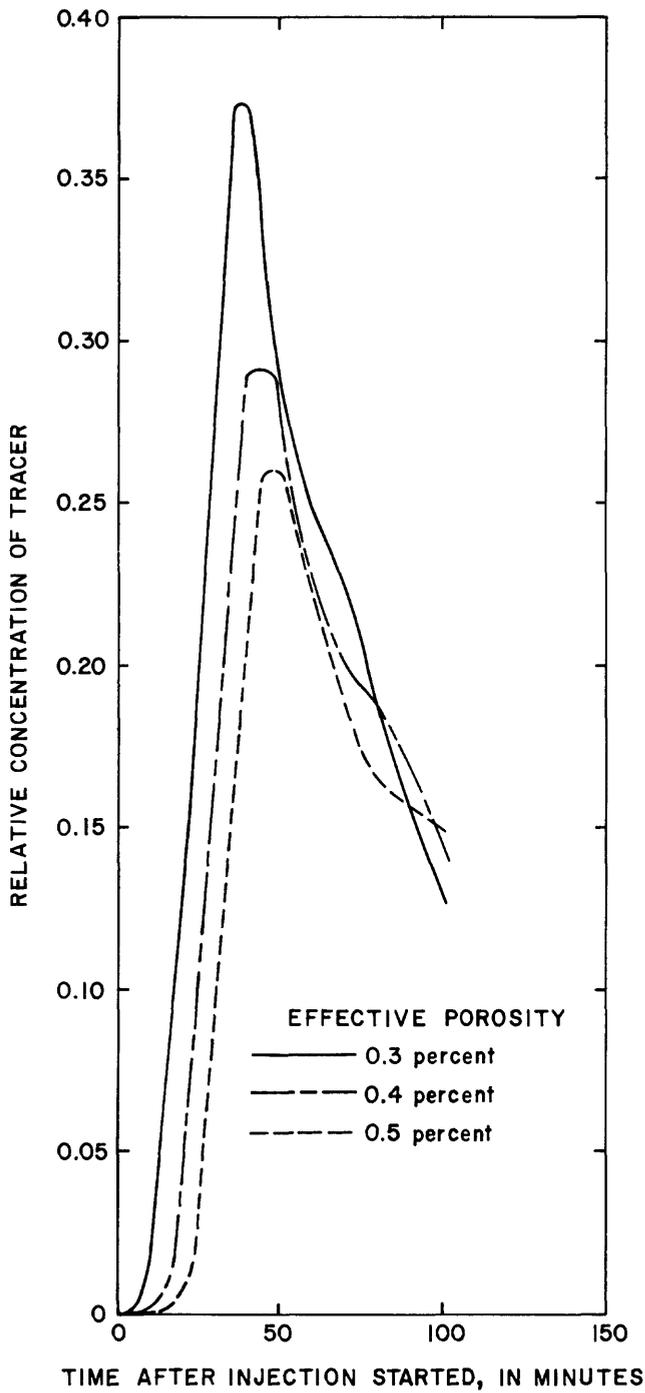


Figure 12.--Theoretical breakthrough curves for various values of effective porosity with a dispersion constant of 1 foot, West Decker Mine spoils.

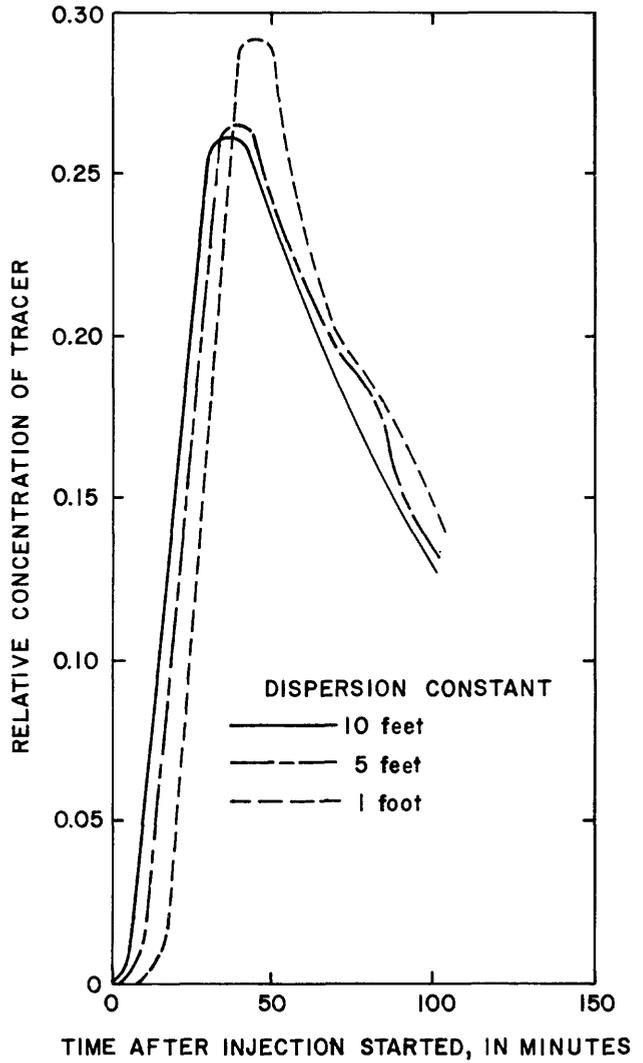


Figure 13.--Theoretical breakthrough curves for various values of dispersion constant with an effective porosity of 0.4 percent, West Decker Mine spoils.

fer, the results of the tests probably indicate only the general magnitude of the effective porosity. Because of the test method, the determined effective porosity may represent only the fracture effective porosity of a dual-porosity system.

Digital simulation model of the West Decker Mine area

General description and assumptions

Water flow in the Anderson-Dietz 1 coal aquifer and other hydrologically connected aquifers is dependent upon the hydrologic properties of the system. A computer program written by Trescott and others (1976) was used to model the hydrologic system. Solution was by the strongly implicit procedure (SIP). The development of the model of the Decker area requires that certain assumptions be made about the hydrologic system. The major assumptions made in this study are:

1. Flow in the aquifer is consistent with Darcy's law.
2. At any given point in the aquifer, the vertical-flow component is negligible in comparison to the two-dimensional horizontal-flow component.
3. The aquifer is anisotropic with respect to hydraulic conductivity in the horizontal direction.
4. Density of the water is constant in time and space.
5. Recharge to the aquifer is constant with time.
6. Hydrologic conditions outside of the study area that could affect the hydrologic conditions inside the study area will not change appreciably.

If additional data or future conditions indicate that these assumptions are invalid, then any simulation made with the model will need to be reevaluated.

Finite-difference grid and boundary conditions

The Anderson-Dietz 1 coal aquifer was modeled by subdividing the area into a finite-difference grid having 21 rows and 27 columns (fig. 14). Nodes were located at the centers of the grid blocks, which are 0.25 mile on a side. The grid, which is oriented in northwest and northeast directions, aligns with the major and minor axes of anisotropy of hydraulic conductivity.

Several types of boundaries were used in the model. The computer program requires that the modeled area be surrounded by a no-flow boundary consisting of nodes at which the transmissivity equals zero. Along fault zones, the no-flow boundary simulates actual conditions. In other areas, a constant-head boundary, a head-dependent variable-flow boundary, or a constant-flow boundary was placed inside the no-flow boundary.

A constant-head boundary was used to simulate the Tongue River Reservoir. The average stage of the Tongue River Reservoir from 1948 to 1980 was about 3,407 feet above sea level.

A head-dependent variable-flow boundary was used along the southwestern edge of the modeled area. With this type of boundary, a constant head was assigned at a sufficient distance from the modeled area such that any stresses applied within

the modeled area would have no effect on the assigned distant constant head. The head at the boundary of the modeled area, however, was allowed to vary, and the flow to that area was calculated by:

$$Q = K \cdot b \cdot \frac{(H_c - h)}{d} \cdot \Delta y \quad (9)$$

where

- Q is the volume of flow per unit of time (L^3/T , where L is length and T is time);
- K is the horizontal hydraulic conductivity (L/T);
- b is the saturated thickness of the aquifer (L);
- H_c is the assigned distant constant head (L);
- h is the head at the boundary of the modeled area (L);
- Δy is the grid increment in the y direction (L); and
- d is the horizontal distance over which the head difference is calculated (L).

The flow at this boundary was calculated in the leakage option of the program. Steady-state leakage is calculated by:

$$Q = K_v \cdot \frac{(H_r - h)}{m} \cdot \Delta x \cdot \Delta y \quad (10)$$

where

- Q is the volume of flow per unit of time (L^3/T);
- K_v is the vertical hydraulic conductivity of the confining layer (L/T);
- H_r is the head on the side of the confining layer opposite the aquifer (L);
- h is the head in the aquifer (L);
- $\Delta x, \Delta y$ are the grid increments in the x and y directions, respectively (L); and
- m is the thickness of the confining layer (L).

To simulate the flow at the boundary using the leakage option of the program, equations 9 and 10 are set equal. With some rearrangement, the following is true:

$$Q = \frac{K \cdot b}{\Delta x} \cdot \frac{(H_c - h)}{d} \cdot \Delta x \cdot \Delta y = K_v \cdot \frac{(H_r - h)}{m} \cdot \Delta x \cdot \Delta y \quad (11)$$

Therefore, for use in the model, the value for K_v is replaced by the value of the quantity $(K \cdot b)/\Delta x$, the value for m is replaced by the value of d, and the value for H_r is replaced by the value for H_c along the western boundary.

A constant-flow boundary was used along the northwestern edge of the model area. The flows were determined from a calibrated steady-state simulation in which a constant-head boundary was used along the northwestern edge. The constant-flow boundary is used instead of a head-dependent variable-flow boundary owing to a lack of hydrologic data outside this part of the study area. Therefore, the results of any simulation, other than one simulating pre-mining steady-state conditions, must be analyzed with respect to the magnitude and direction of possible errors resulting from use of the constant-flow boundary along the northern edge. For all simulations in this study, the effects were considered to be minimal.

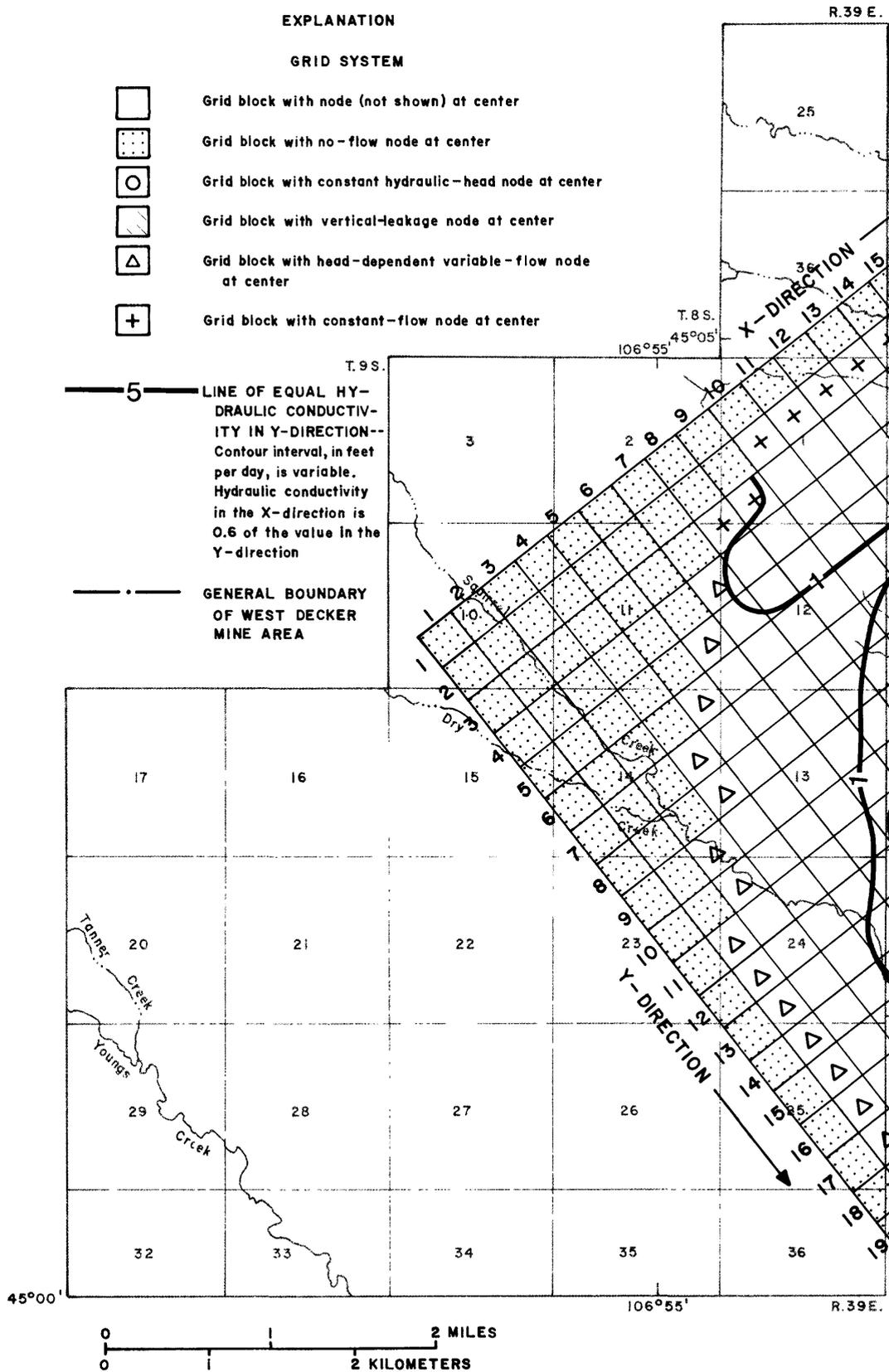
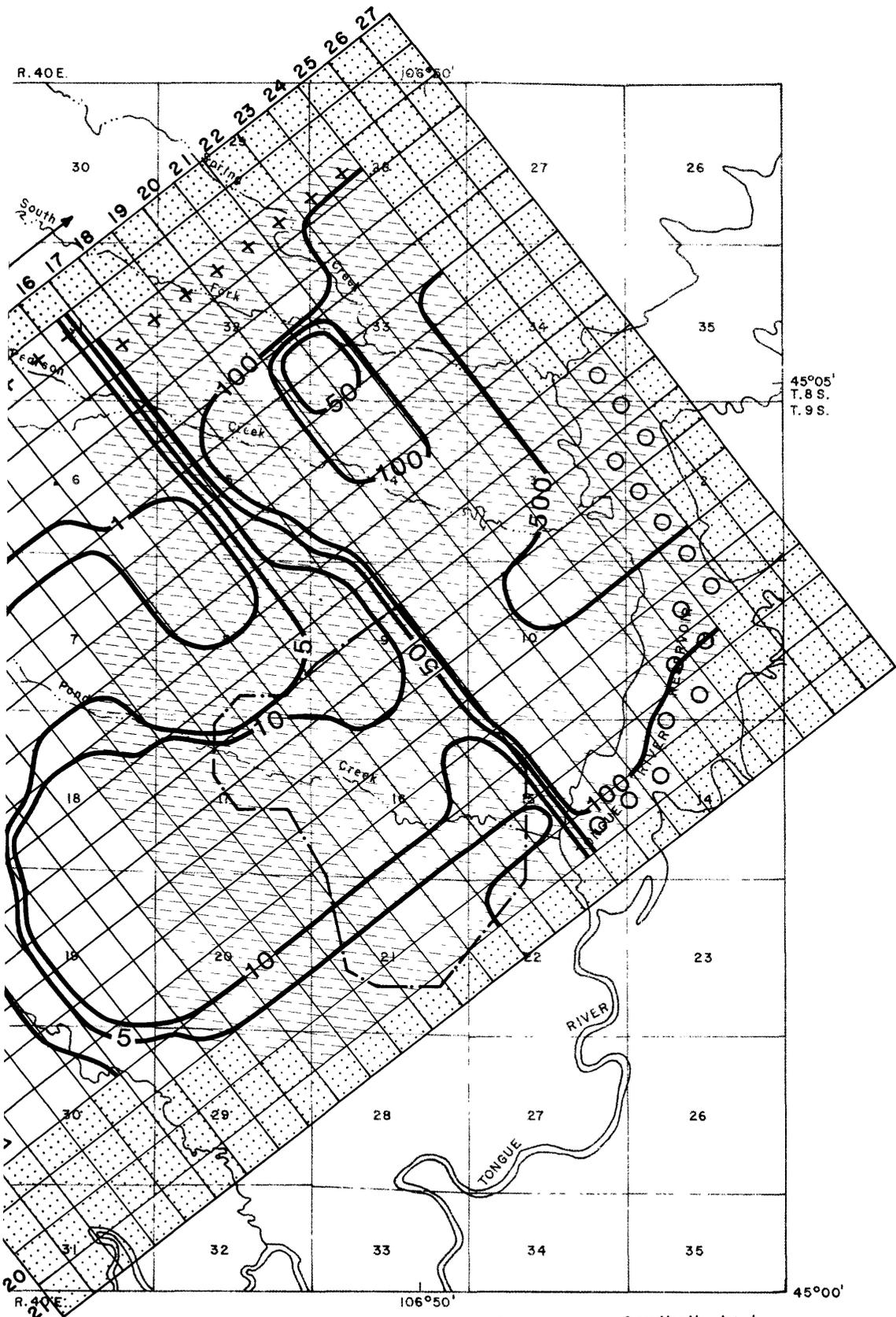


Figure 14.--Finite-difference grid and hydraulic conductivity



Boundary of mine area from Van Voast and Hedges (1975)

for West Decker Mine modeled area.

Vertical leakage was simulated in the model for the area where the Dietz 2 coal and the Anderson-Dietz 1 coal are separated by interburden. The interburden, or confining layer, ranges in thickness from 5 to 65 feet (Cole and Sholes, 1980, p. 6). The direction of leakage was determined by the hydraulic head in the coal beds. For pre-mining steady-state conditions, the direction of leakage generally is downward from the Anderson-Dietz 1 coal bed in the northeastern part of the modeled area and upward into the Anderson-Dietz 1 coal bed in the southeastern part of the modeled area (Van Voast and Hedges, 1975, pls. 4 and 5).

Modifications

The modeling program was modified to print leakage flow and constant-head flow node-by-node instead of only as a summation. This change has no effect on the solution and therefore is not listed here.

The program also was modified to properly allow for leakage to and from an underlying source bed with the combined artesian-water table option. As documented in Trescott and others (1976), the original program was designed to calculate leakage from an overlying source bed. If the combined artesian-water table option (CONVRT) is designated, the hydraulic head in the aquifer is set to the greater of either the altitude of head or the altitude of the top of the aquifer for the leakage calculation. For water-table conditions with vertical leakage to the aquifer from an underlying source bed, the calculated vertical gradient will be in error. Therefore, to correct the calculation of vertical gradient, the dependence of the gradient on the altitude of the top of the aquifer was eliminated. Because only steady-state simulations were computed by the model and because the underlying source bed is everywhere confined, only the steady component of leakage required modification. The program was modified as follows:

1. Statement SIP1550 was changed to read
HED1=STRT(N) SIP1550*;
2. Statements SIP1570, SIP1580, SIP1590, and SIP1600 were eliminated;
3. Statement SIP1610 was changed to read
190 SL(N)=RATE(N)/M(N)*(RIVER(N)-HED1) SIP1610*;
4. Statement SIP2590 was changed to read
HED1=STRT(N) SIP2590*;
5. Statements SIP2610; SIP2620, SIP2630, and SIP2640 were eliminated;
6. Statement SIP2650 was changed to read
320 SL(N)=RATE(N)/M(N)*(RIVER(N)-HED1) SIP2650*;
7. Statements CHK1180 and CHK1200 were eliminated.

The original statements are listed in Trescott and others (1976, p. 93, 95, and 111). Model simulations made with changes to the program are valid only for steady-state simulations with leakage to and from an underlying source bed that is everywhere confined.

Calibration and sensitivity analysis

Steady-state calibration of the model consisted of adjustment of the values of the hydrologic parameters, which govern the ground-water flow, until the calculated head distribution accurately simulated the measured head distribution. The data input to the model that were not adjusted during calibration included altitude of

the base of the aquifer, altitude of the top of the aquifer, altitude of the initial potentiometric surface, thickness of the interburden or confining layer, and altitude of the potentiometric surface in the underlying Dietz 2 coal. The values of these parameters are relatively accurately known. Values for hydraulic conductivity, vertical hydraulic conductivity, and recharge were not known as accurately and, therefore, were adjusted within a reasonable range during calibration. The ratio of hydraulic conductivity in the northeast direction to hydraulic conductivity in the northwest direction used in the model was 0.6 to 1.

Hydraulic-conductivity values, as determined from calibration of the model, are shown in figure 14. Hydraulic conductivity of the coal in the northwest-southeast direction ranged from 0.50 to 50 ft/d and averaged 7.1 ft/d. Hydraulic conductivity in the northeast-southwest direction ranged from 0.30 to 30 ft/d and averaged 4.3 ft/d. These values compare favorably with the average of 5.2 ft/d determined from aquifer tests.

Values of hydraulic conductivity used in the model for the clinker and alluvium ranged from 60 to 600 ft/d and averaged 240 ft/d for the northwest-southeast direction. In the northeast-southwest direction, hydraulic conductivity of the clinker and alluvium ranged from 36 to 360 ft/d and averaged 140 ft/d. Actual values of the hydraulic conductivity of the clinker and alluvium and the direction and ratio of anisotropy are unknown.

The value used for vertical hydraulic conductivity of the interburden was 0.00007 ft/d. This value is about 100 times smaller than the geometric mean of horizontal hydraulic conductivity determined by Rehm and others (1980, p. 552) for aquitards in the northern Great Plains. However, values for vertical hydraulic conductivity are commonly 100 times smaller than values for horizontal hydraulic conductivity (Freeze and Cherry, 1979, p. 34). Therefore, the value used is considered to be valid and representative.

A value of 0.6 inch was used for the rate of annual recharge in areas underlain by clinker and alluvium. All other areas were considered to receive no recharge from the surface. Although annual recharge was not measured directly, the value of 0.6 inch produced the closest match of calculated to observed hydraulic heads in the area of clinker and alluvium using the aforementioned values of hydraulic conductivity.

The mean difference between observed hydraulic head and the hydraulic head calculated by the calibrated steady-state pre-mining model simulation was -0.03 foot. The absolute value of the difference at any one node was less than 10 feet. These differences are considered acceptable because many of the altitudes of wells used to construct the pre-mining potentiometric-surface map were known only to ± 10 feet.

The flows computed by the pre-mining steady-state model simulation are shown below:

	Rate (cubic feet per second)
Recharge	0.3449
Constant-flow from northern boundary	3.7453
Head-dependent flow from western boundary	0.0509
Upward leakage into Anderson-Dietz 1 coal bed	0.0650
Downward leakage out of Anderson-Dietz 1 coal bed	-0.0904
Constant-head flow to Tongue River Reservoir	<u>-4.1150</u>
Sum	0.0007

These flows are within the range of rates estimated for pre-mining conditions in the aquifer. The rates do not sum to zero because of rounding.

The sensitivity of the pre-mining steady-state model to changes in hydraulic conductivity, recharge rate, vertical hydraulic conductivity of underlying confining layer, and ratio of anisotropy of hydraulic conductivity is shown in figures 15 and 16. All changes represent a 15-percent increase or decrease for the respective parameters throughout the modeled area except for recharge, which was changed only where it was initially greater than zero. The figures show that the most sensitive parameter is the hydraulic conductivity of the Anderson-Dietz 1 coal bed. The least-sensitive parameter is the recharge rate, probably because of the localized extent of the recharge area. If data-collection activities occur in the future, it would be important to consider determination of hydraulic conductivity and the ratio of anisotropy.

Results of model simulations

The model was used to simulate the effects of the mine spoils on the surrounding hydrologic system for post-mining equilibrium conditions. Two simulations were made, each with different values for the hydraulic characteristics of the spoils. The area of the spoils coincides with the area within the West Decker Mine boundary (fig. 7).

The direction and ratio of anisotropy of hydraulic conductivity of the spoils are unknown. In the model, the same direction and ratio of anisotropy were used for the spoils as were used for the coal aquifer. Owing to the paucity of data, this usage is considered valid within the limited knowledge of the hydrologic system of the spoils.

Simulation 1 was made assuming a uniform value of 5 ft/d for hydraulic conductivity in the northwest-southeast direction and an effective saturated thickness of 20 feet, resulting in a transmissivity of 100 ft²/d. In the northeast-southwest direction, hydraulic conductivity was assumed to be 3 ft/d with an effective saturated thickness of 20 feet, resulting in a transmissivity of 60 ft²/d. These values compare closely to values determined from aquifer tests and are believed to be a reasonable approximation of conditions in the spoils. The results of this simulation (fig. 17) show an increase in hydraulic head upgradient from the mine area. The maximum increase in head of almost 12 feet is near the western edge of the

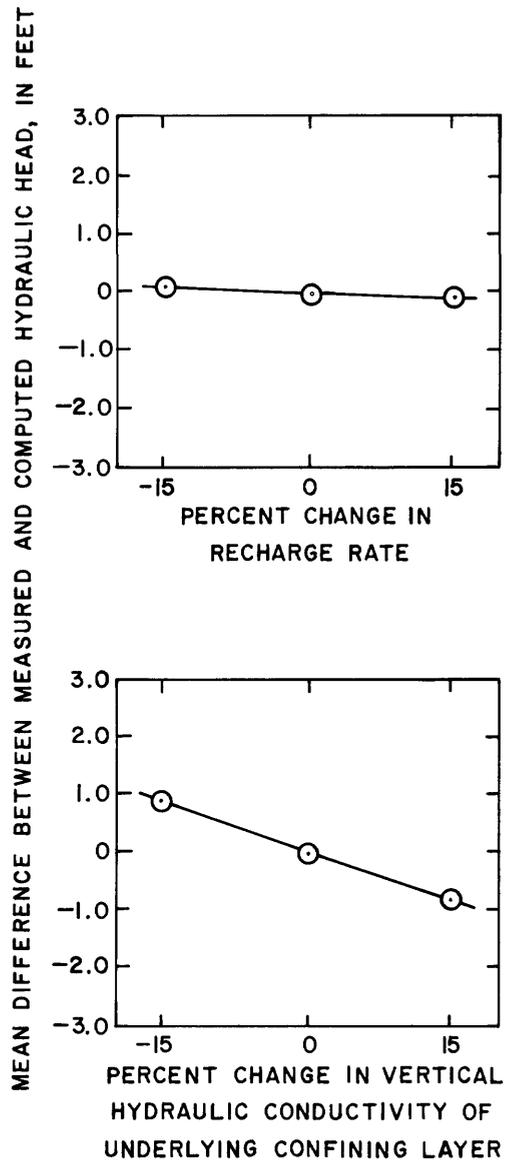
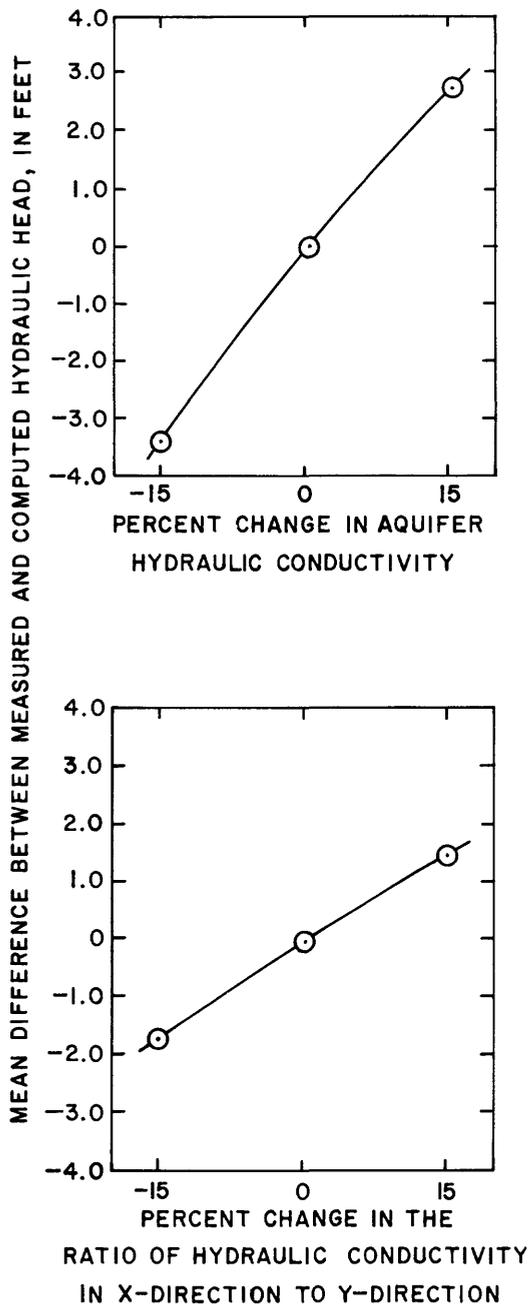


Figure 15.--Sensitivity of computed hydraulic head in the modeled area to changes in aquifer hydraulic conductivity and the ratio of hydraulic conductivity in the x-direction to the y-direction, West Decker Mine modeled area.

Figure 16.--Sensitivity of computed hydraulic head in the modeled area to changes in recharge rate and vertical hydraulic conductivity of underlying confining layer, West Decker Mine modeled area.

mine area, and the increases diminish westward and northward. At the constant-flow boundary along the northern edge (fig. 14), the maximum increase in head is 5 feet. In a situation of increased head, the effect of the constant-flow boundary

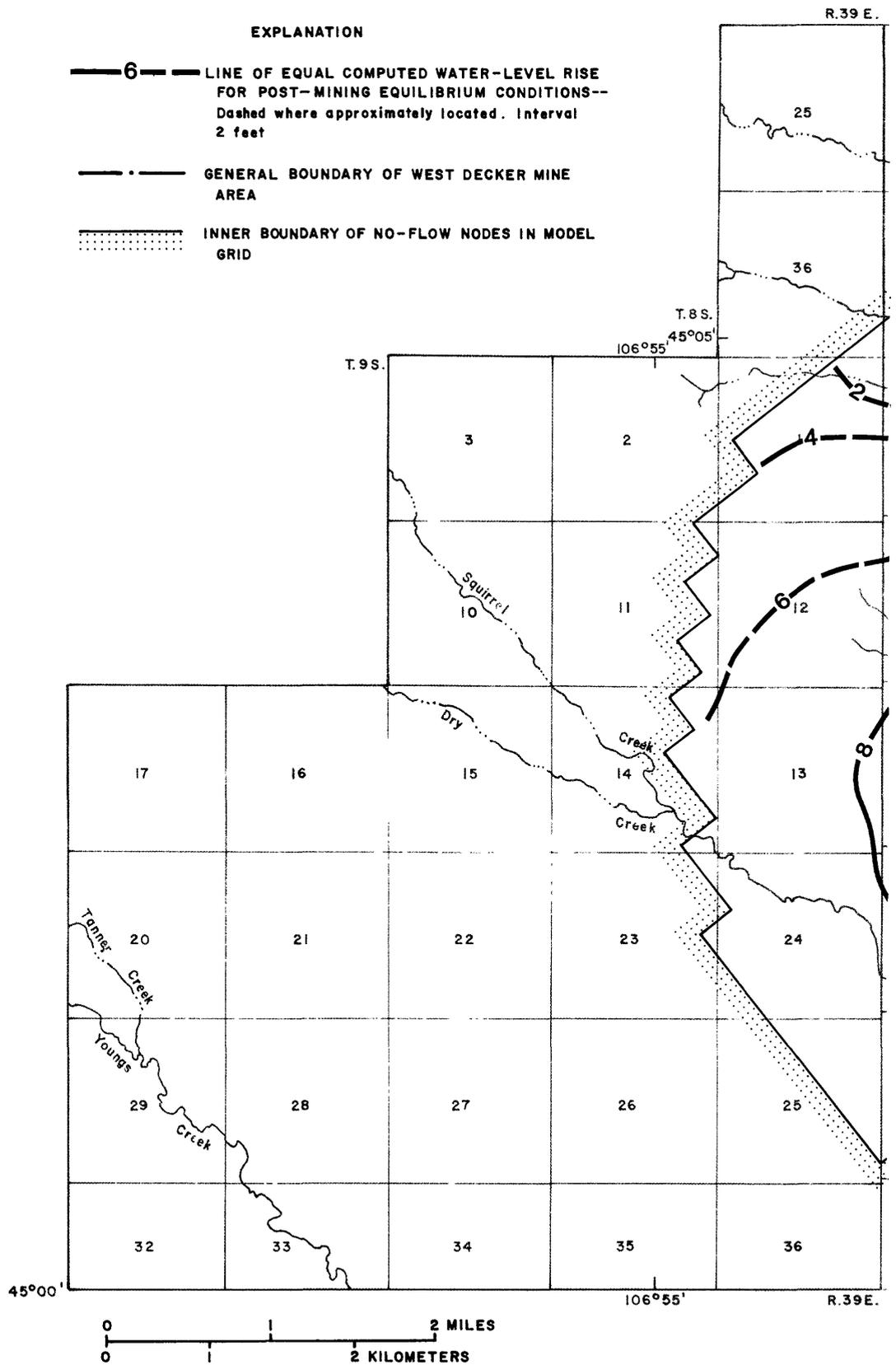
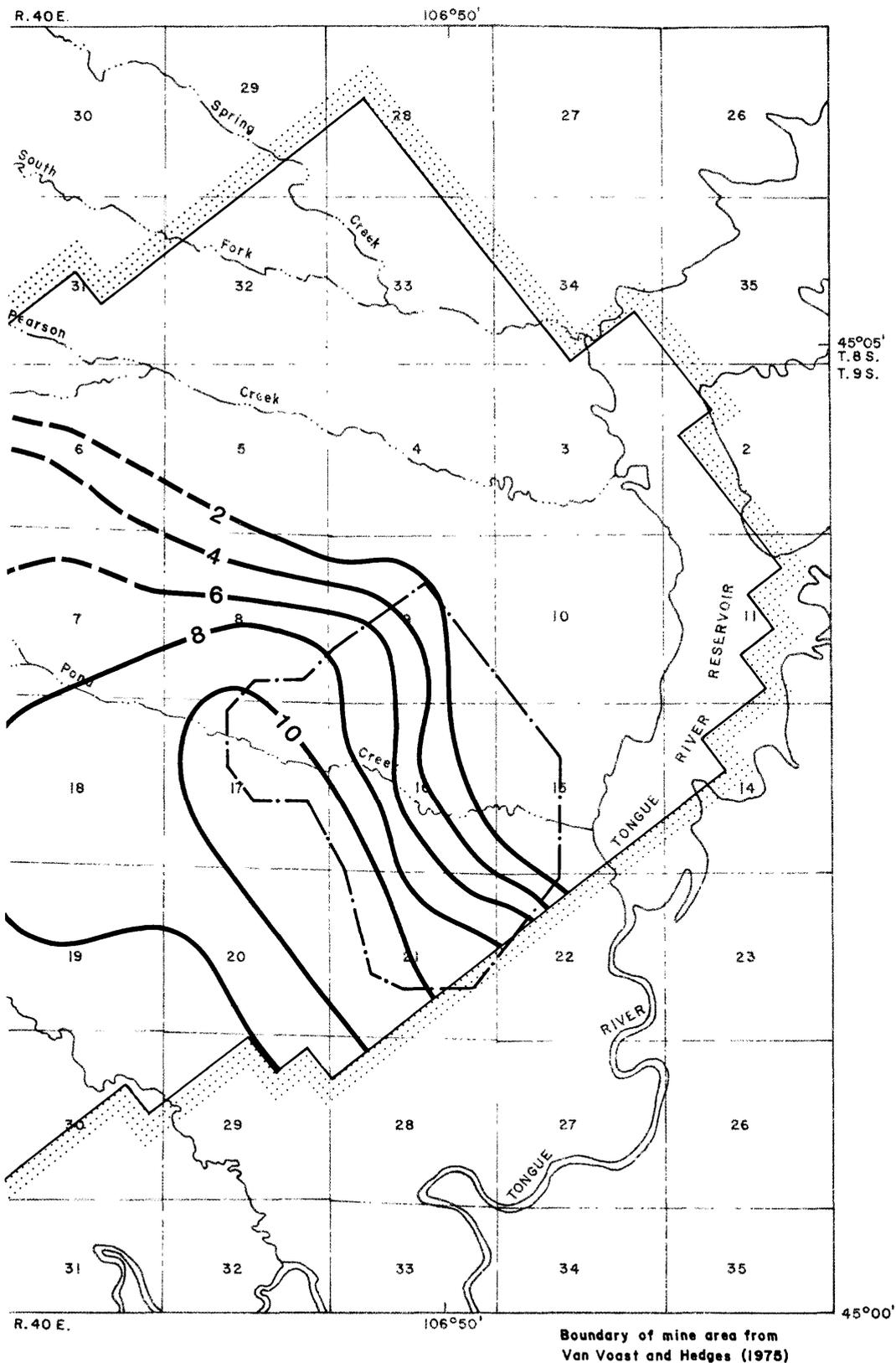


Figure 17.--Water-level rise computed by simulation 1 for post-



mining equilibrium conditions, West Decker Mine modeled area.

would be to cause additional increase in head. Therefore, the effect of the constant-flow boundary along the northern edge certainly is less than 5 feet and probably is less than 1 foot.

Simulation 2 was made to determine the effects that an underestimation of transmissivity, as used in simulation 1, might have on the surrounding hydrologic system at post-mining equilibrium. This simulation was made assuming the same values for hydraulic conductivity as in simulation 1, but an effective saturated thickness of 40 feet was used, which resulted in a transmissivity of 200 ft²/d in the northwest-southeast direction and 120 ft²/d in the northeast-southwest direction. These values are twice the values used in simulation 1. The results of this simulation (fig. 18) also show an increase in hydraulic head upgradient of the mine area. The maximum increase in head of almost 8 feet is near the western edge of the mined area, and the increases diminish westward and northward. At the constant-flow boundary along the northern edge (fig. 14), the maximum increase in head is 3 feet. Using the same reasoning as for simulation 1, the effect of the constant-flow boundary along the northern edge certainly is less than 3 feet and probably is less than 1 foot.

The increase in head upgradient of the mine area, as shown in both simulations 1 and 2, results from the transmissivity of the spoils being smaller than the transmissivity of the coal aquifer they replace. The maximum transmissivity of the spoils in either simulation was 200 ft²/d, whereas the modeled transmissivity of the original coal aquifer within the mine boundary was generally greater than 250 ft²/d.

The flows computed by the post-mining steady-state model simulations are shown below:

	Rate, in cubic feet per second, <u>for simulation 1</u>	Rate, in cubic feet per second, <u>for simulation 2</u>
Recharge	0.3449	0.3449
Constant flow from northern boundary	3.7453	3.7453
Head-dependent flow from western boundary	0.0488	0.0495
Upward leakage into Anderson-Dietz 1 coal bed	0.0393	0.0470
Downward leakage out of Anderson-Dietz 1 coal bed	-0.1412	-0.1224
Constant-head flow to Tongue River Reservoir	<u>-4.0363</u>	<u>-4.0638</u>
Sum	0.0008	0.0005

The rates do not sum to zero because of rounding.

Geochemistry

Existing water quality and geochemical processes

Water in the coal aquifers in the West Decker area has an average dissolved-solids concentration of about 1,400 mg/L (milligrams per liter) and is primarily a sodium bicarbonate type. The percentage of total milliequivalents per liter for the major ions, as determined from the most recent and representative analyses in table 2, is shown in figure 19.

Water in the spoils aquifer has an average dissolved-solids concentration of about 2,500 mg/L. The spoils water also is mainly a sodium bicarbonate type (fig. 19), although it tends to have a larger percentage of total milliequivalents per liter of calcium plus magnesium and of sulfate plus chloride than water from the coal aquifers.

The equilibrium relationships, determined using the program WATEQF, between water from selected wells completed in the coal aquifers and selected mineral species are given in table 4. Saturation indices indicate that water from the coal aquifers generally is saturated or supersaturated with respect to quartz and undersaturated with respect to gypsum and anhydrite. Water from some wells is undersaturated or near saturation with respect to calcite, aragonite, dolomite, and magnesite, although aragonite and magnesite have not been determined to be present in either the coal or clastic facies of the Tongue River Member. Only one analysis of water from the coal had sufficient information to determine the degree of saturation with respect to albite, which is a sodic feldspar that can weather to sodic clay. This analysis (09S40E09DCAB01) showed undersaturation with respect to albite.

The relationship between water from selected wells completed in the spoils aquifer and selected mineral species is given in table 5. The saturation indices indicate that water from the spoils aquifer generally is saturated or supersaturated with respect to quartz, calcite, aragonite, dolomite, magnesite, and albite, and undersaturated with respect to gypsum and anhydrite.

The undersaturation with respect to gypsum for water from both the coal aquifers and the spoils aquifer implies either a lack of pyrite in the overburden and spoils or a lack of surface recharge through the overburden and spoils, or both. The general undersaturation of water from the coal aquifers with respect to calcite, aragonite, dolomite, and magnesite indicates that water in the coal aquifers has limited contact with the clastic facies of the Tongue River Member. The general undersaturation also indicates a lack of surface recharge through the overburden.

The general state of saturation or supersaturation of water from the spoils aquifer denotes that the dissolved-solids concentration is near maximum. The concentration will not increase significantly, assuming that solute sources and temperature do not change.

The geochemical processes that determine the quality of water in the coal aquifers are predominantly the dissolution of silica, sulfate, and carbonate minerals in the recharge areas. Most of the calcium and magnesium from the carbonate minerals is exchanged for sodium by reactions with either sodic clays in the clinker or with the coal itself. Sulfate-reducing bacteria probably decrease the concentration of sulfate and increase the concentration of bicarbonate (Dockins and others, 1980).

Projection of future water quality

Batch-mixing experiments were conducted to determine ground-water-quality changes that might occur as a result of mining. Water from the Anderson-Dietz 1 coal bed was mixed with spoils material to try to simulate previously observed changes in quality. Spoils material from the southern and northern parts of the West Decker Mine were used. Spoils material from the northern part contained more

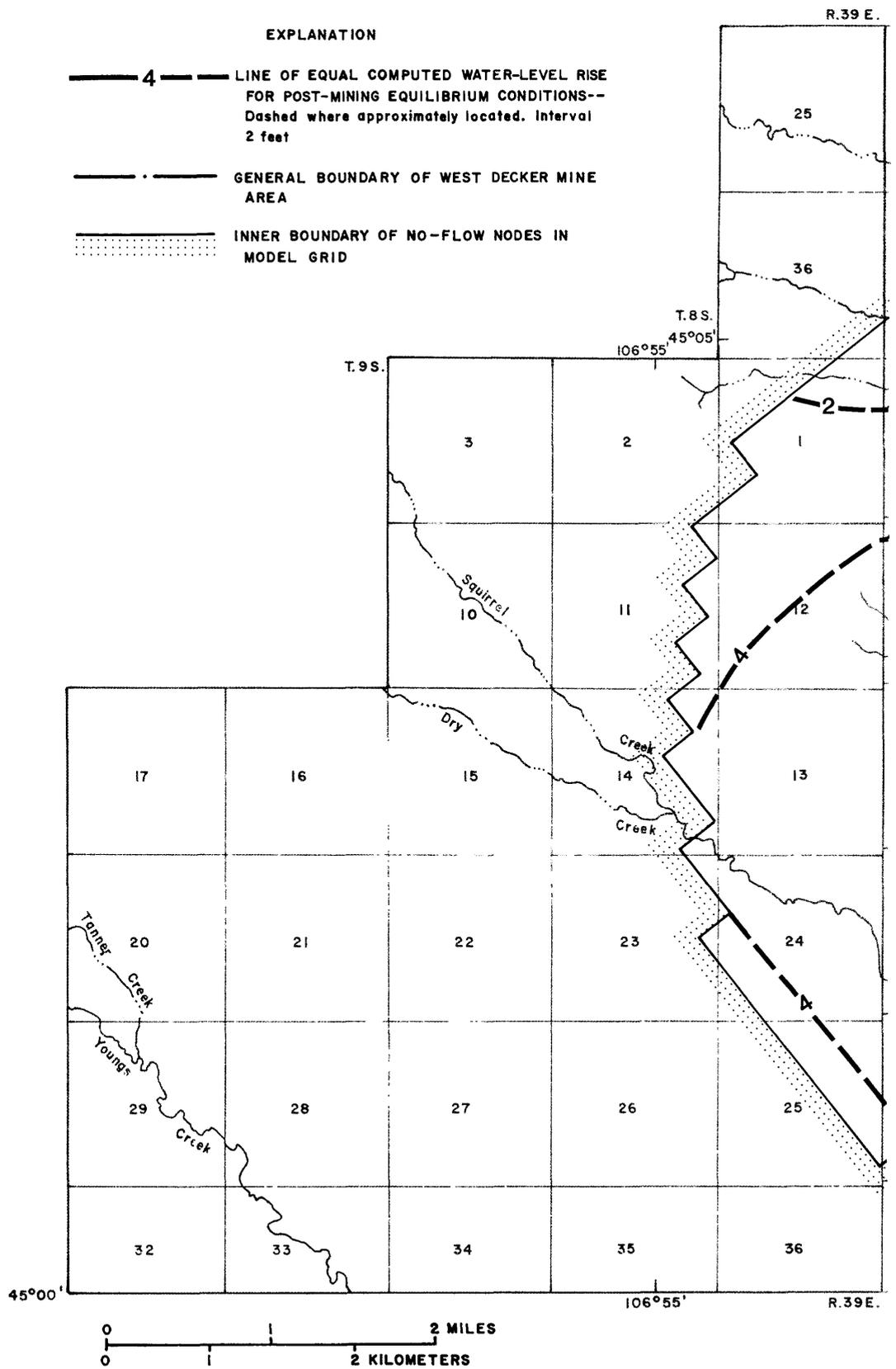
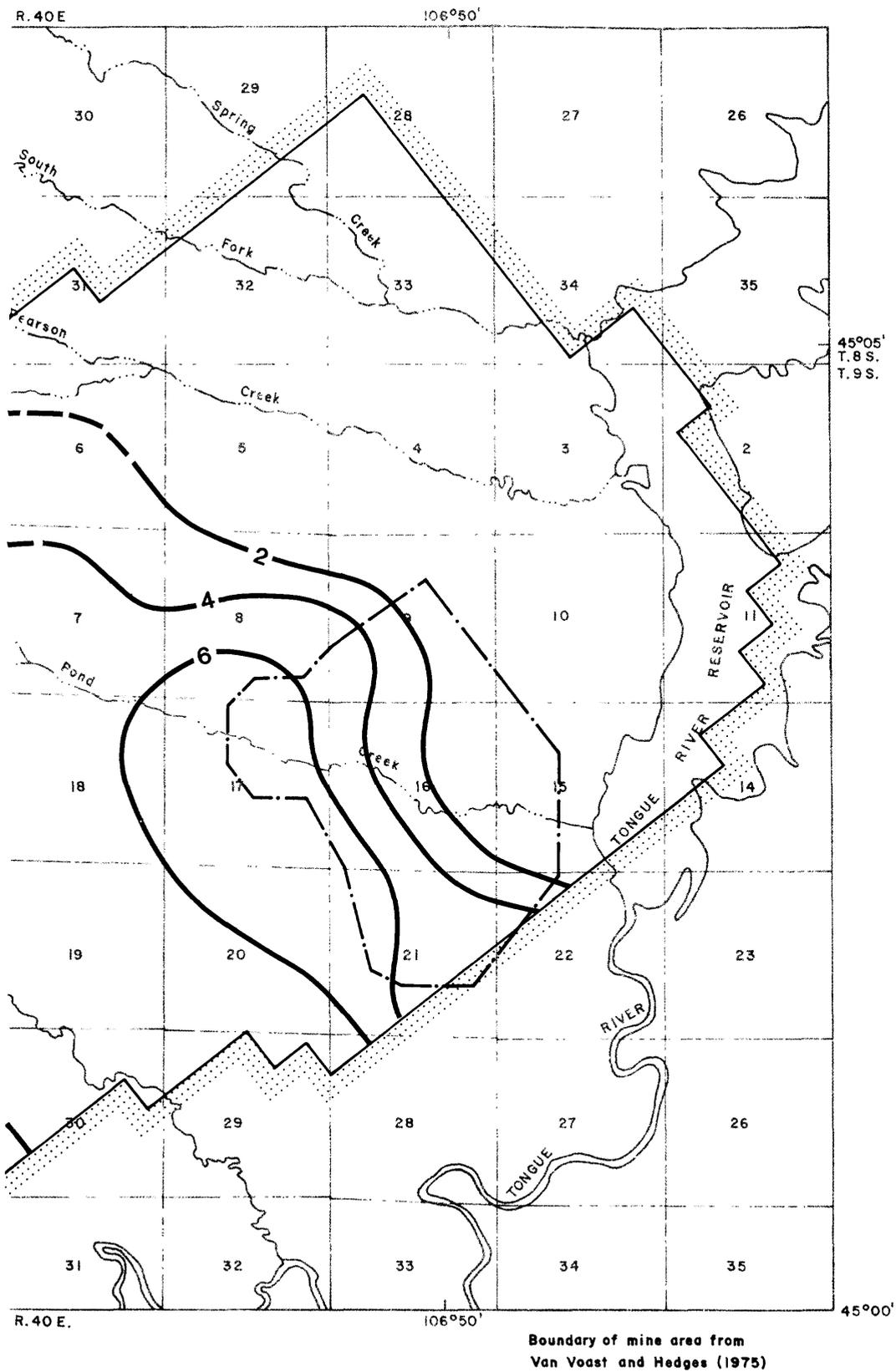
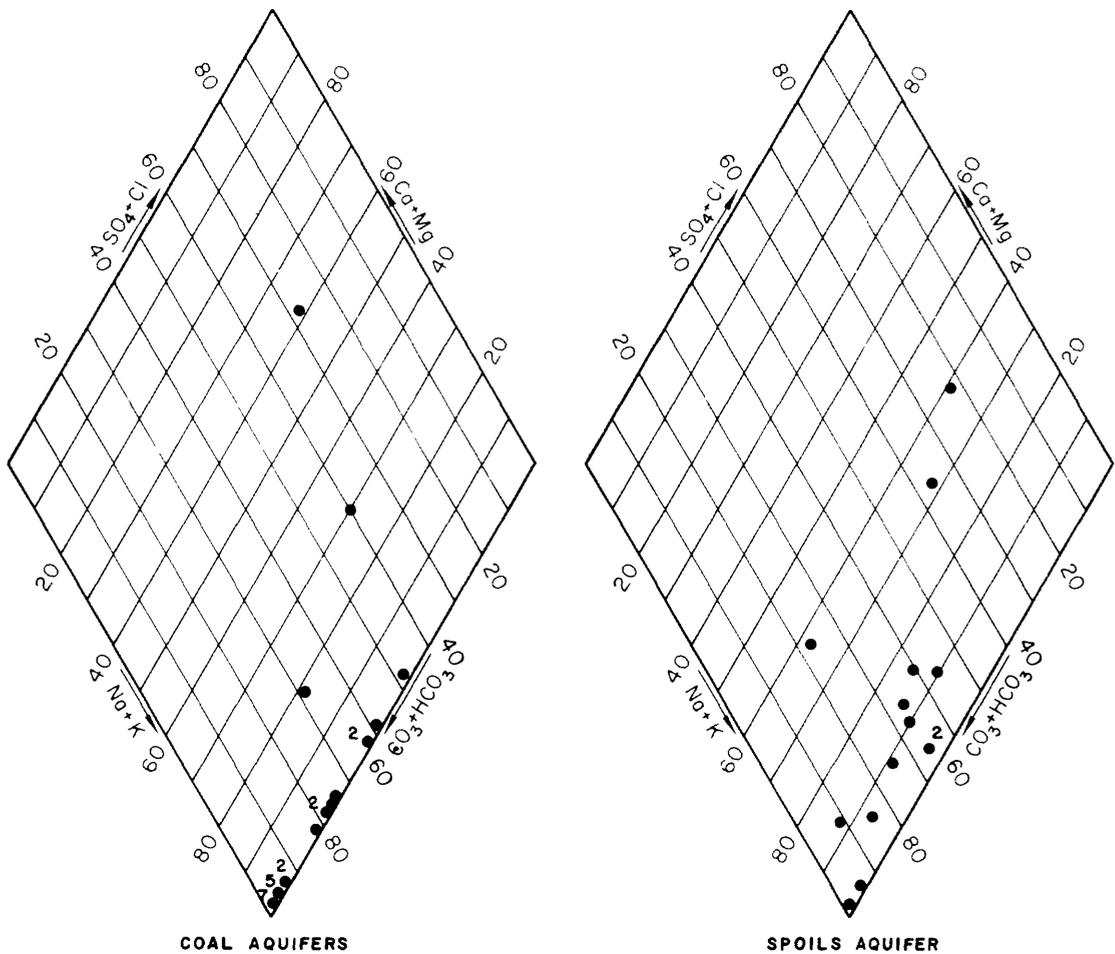


Figure 18.--Water-level rise computed by simulation 2 for post-



mining equilibrium conditions, West Decker Mine modeled area.



EXPLANATION

- 5 ● DATA POINT-- Numeral
Indicates number of analyses
plotted at the same location,
if more than 1

ALL SCALES ARE IN PERCENTAGE
OF TOTAL MILLIEQUIVALENTS
PER LITER

Figure 19.--Water-analysis diagrams for water from wells, West Decker Mine study area.

clay than material from the southern part. Water from the spoils aquifer was mixed with coal to determine water-quality changes that might occur after mining is completed if water from the spoils flows back through a coal aquifer.

The resulting differences in pH and dissolved solids between the pre-mixing, or control, water samples and the post-mixing water samples are shown in figure 20. In general, water from the coal aquifer mixed with spoils material showed an increase in pH of a few tenths of a unit. The increase in dissolved-solids concentration for the coal-aquifer water and spoils material, mixed in a ratio of 2:1 by weight, is similar to increases observed at some wells. The mixture of a 5:1 ratio

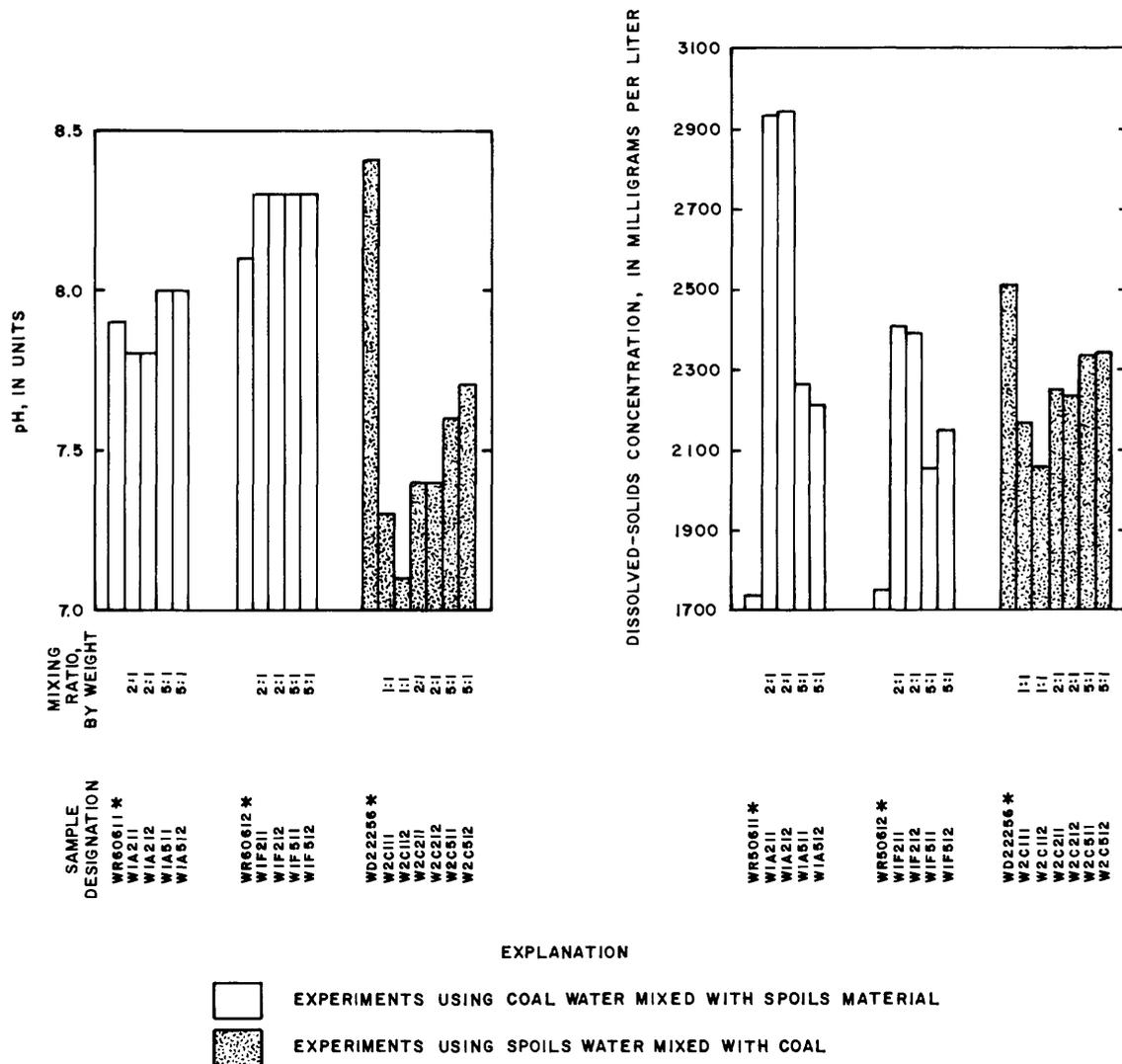


Figure 20.--Changes in pH and dissolved-solids concentration resulting from batch-mixing experiments using materials from the West Decker Mine study area. The asterisks designate the control samples.

showed lesser increases, indicating that the amount of soluble material was the limiting factor.

In comparison to the control samples, the mixtures of coal-aquifer water and spoils material from the southern part of the West Decker Mine showed general increases in concentrations of calcium, magnesium, sodium, potassium, sulfate, copper, manganese, and strontium (tables 6 and 7) and general decreases in concentrations of titanium and zinc. Mixtures using material from the northern part of the West Decker Mine showed similar changes, except that concentrations of calcium, magnesium, potassium, sulfate, and strontium increased less, concentrations of titanium tended to increase, and concentrations of zinc remained unchanged.

The amount of water in a 2:1 mixture of water and spoils material represents almost 900 effective pore volumes, based on a specific gravity of 1.75 for the

spoils material and an effective porosity of the spoils of 0.4 percent. Similarly, the amount of water in a 5:1 mixture represents almost 2,200 effective pore volumes.

The average velocity of water moving through the spoils is estimated to be 3 ft/d, based on a post-mining gradient of 22 ft/mi, a hydraulic conductivity of 3 ft/d, and an effective porosity of 0.4 percent. If the average width of the spoils aquifer is 1.25 miles, then 2,200 days (6 years) will be required for water moving at the average velocity to flow through the spoils. The passage of 900 effective pore volumes would take 5,400 years, and the passage of 2,200 effective pore volumes would take about 13,000 years. If the actual effective porosity is greater than that determined experimentally, the average velocity would be less than 3 ft/d, and the number of effective pore volumes represented by the 2:1 mixture would be less than 900 and the 5:1 mixture would be less than 2,200. However, any substantial decrease in dissolved-solids concentration due to the limiting factor of soluble material in the spoils will be in the distant future.

In comparison to the control sample, mixtures of water from the spoils with coal showed a decrease in pH of about 1 unit and a decrease in dissolved-solids concentration of several hundred milligrams per liter. Concentrations of calcium, magnesium, sodium, potassium, bicarbonate, chloride, strontium, and zinc showed general decreases and concentrations of iron, manganese, fluoride, and boron showed general increases. Concentrations of sulfate remained essentially unchanged.

The processes by which the changes occur are not known. Possible processes are ion exchange with the coal or chemical reaction with impurities in the coal. Another possibility is dilution of the mixing water by water held within the coal. Although the coal used in the experiments was air dried, analyses show that moisture content of the Anderson and Dietz coals ranges from about 20 to about 30 percent (Matson and Blumer, 1973, p. 78). If further experiments are conducted, it would be important to discern which processes predominate. However, if the laboratory experiments conducted for this study are representative of possible future conditions and the observed changes are a real phenomenon, then the dissolved-solids concentration may decrease several hundred milligrams per liter if water from the spoils flows through a coal aquifer.

The amount of water represented by a 1:1 mixture of water and coal is about 430 effective pore volumes, based on a specific gravity of coal of 1.30 and an effective porosity of the coal aquifer of 0.3 percent. The amount of water in a 2:1 mixture represents about 870 effective pore volumes, and the amount of water in a 5:1 mixture represents about 2,200 effective pore volumes.

Effects of mining

The average velocity of water moving through the clinker and alluvium from the spoils to the Tongue River Reservoir is estimated to be about 2 ft/d, based on a gradient of 10 ft/mi, a hydraulic conductivity of 240 ft/d, and an estimated effective porosity for the clinker and alluvium of about 20 percent. The distance from the spoils to the reservoir is about 1.75 miles. Therefore, 4,600 days, or almost 13 years, will be required for water moving at the average velocity to flow from the eastern edge of the spoils to the reservoir.

At post-mining equilibrium, the quantity of water flowing from the spoils area to the reservoir will be about 0.065 ft³/s, based on the results of model simulation 1. If the average dissolved-solids concentration is 1,100 mg/L greater than for pre-mining conditions, the increase in dissolved-solids contribution to the reservoir will be 70.4 tons per year. The dissolved-solids contribution to the reservoir from Tongue River inflow is about 250,000 tons per year, based on an average annual inflow of 508 ft³/s and a dissolved-solids concentration of 500 mg/L (U.S. Geological Survey, 1981, p. 429 and 431). Therefore, the increase in dissolved-solids contribution to the reservoir due to mining will be less than 1 percent of that contributed by the Tongue River.

BIG SKY MINE AREA

Geology

The surface geology in the Big Sky Mine area consists primarily of the Tongue River Member of the Fort Union Formation (fig. 21). The beds being mined are the Rosebud coal, which is about 25 feet thick, and the underlying McKay coal, which is about 10 feet thick. These beds are present mainly in the western half of the study area. In the eastern half, these beds generally have been eroded or burned.

The overburden of the Rosebud coal bed primarily consists of calcareous fine to very fine sand, sandstone, silt, and siltstone with lesser amounts of clay. The interburden between the Rosebud and McKay coal beds primarily consists of calcareous soft shale and siltstone. Ten overburden and spoils samples were collected from an area a few miles north of the Big Sky Mine and analyzed by X-ray diffraction (Hounslow and others, 1978, p. 131-132). Six of these samples are considered by the author to be representative of the general geology and contained, in general descending order of abundance: quartz, dolomite, kaolin, feldspars, mica, and calcite. Samples associated with spoils also contained gypsum and samples associated with iron-rich sandstone, iron-stained spoils, and concretions also contained pyrite. The clay fraction of all samples generally consisted of kaolinite and illite. Smectite was present in significant amounts in only 2 of 10 samples, and vermiculite either was absent or was present only in trace quantities.

Where the Rosebud and McKay coal beds have been eroded or burned, the geology primarily consists of clinker and sandy material of the Tongue River Member. In general, the westernmost areas of clinker are associated with coal stratigraphically above the Rosebud coal bed, and the easternmost areas of clinker are associated with the Rosebud and McKay coal beds.

Alluvium is present along Rosebud Creek. The alluvium consists of silt, sand, and gravel.

Several fault or fracture zones have been postulated in the study area. However, the displacement, if any, along these zones probably is small.

Geohydrology

The location of selected wells in the Big Sky Mine study area is shown in figure 22. Data from these sites are contained in tables 8, 9, and 10.

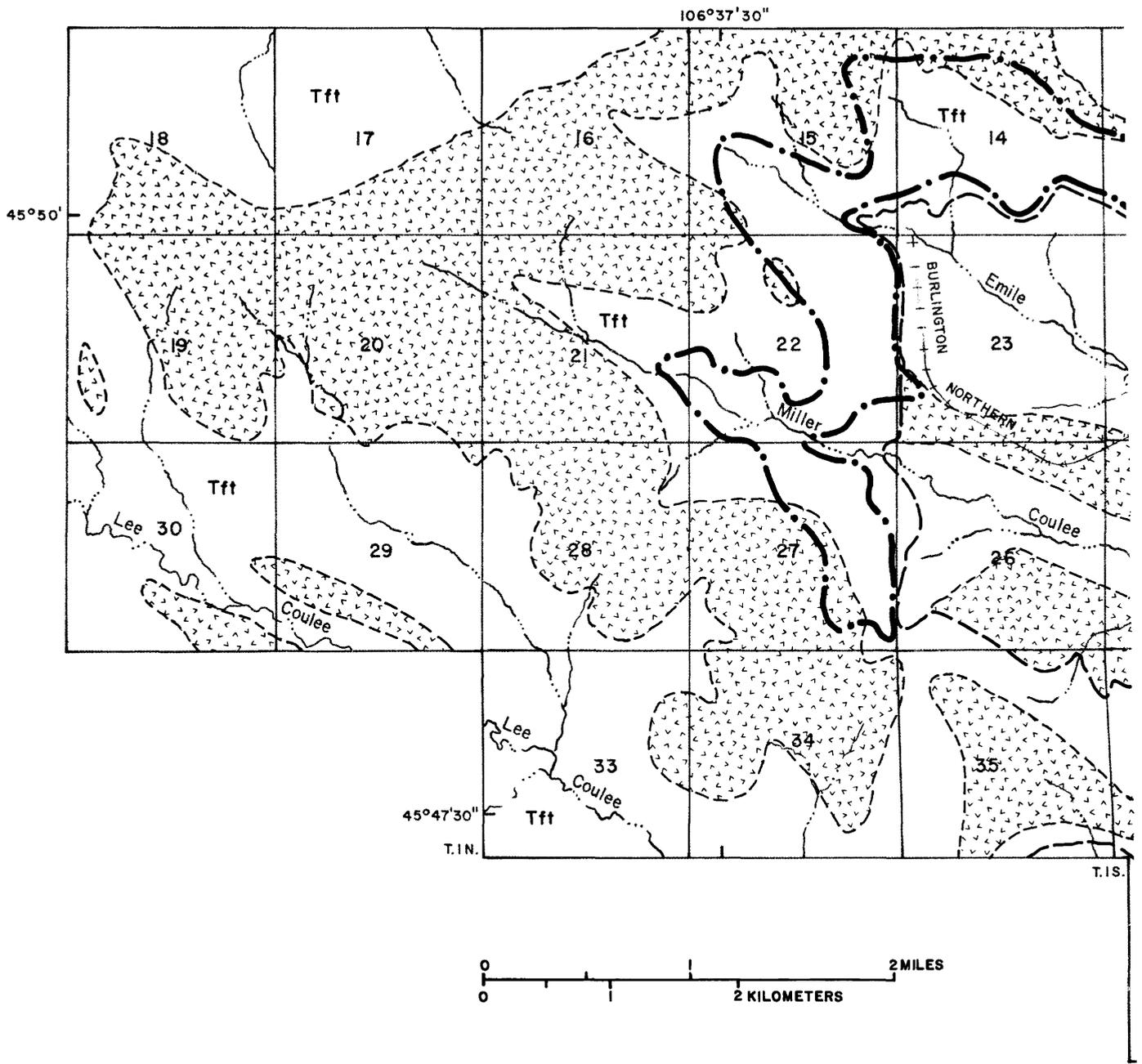
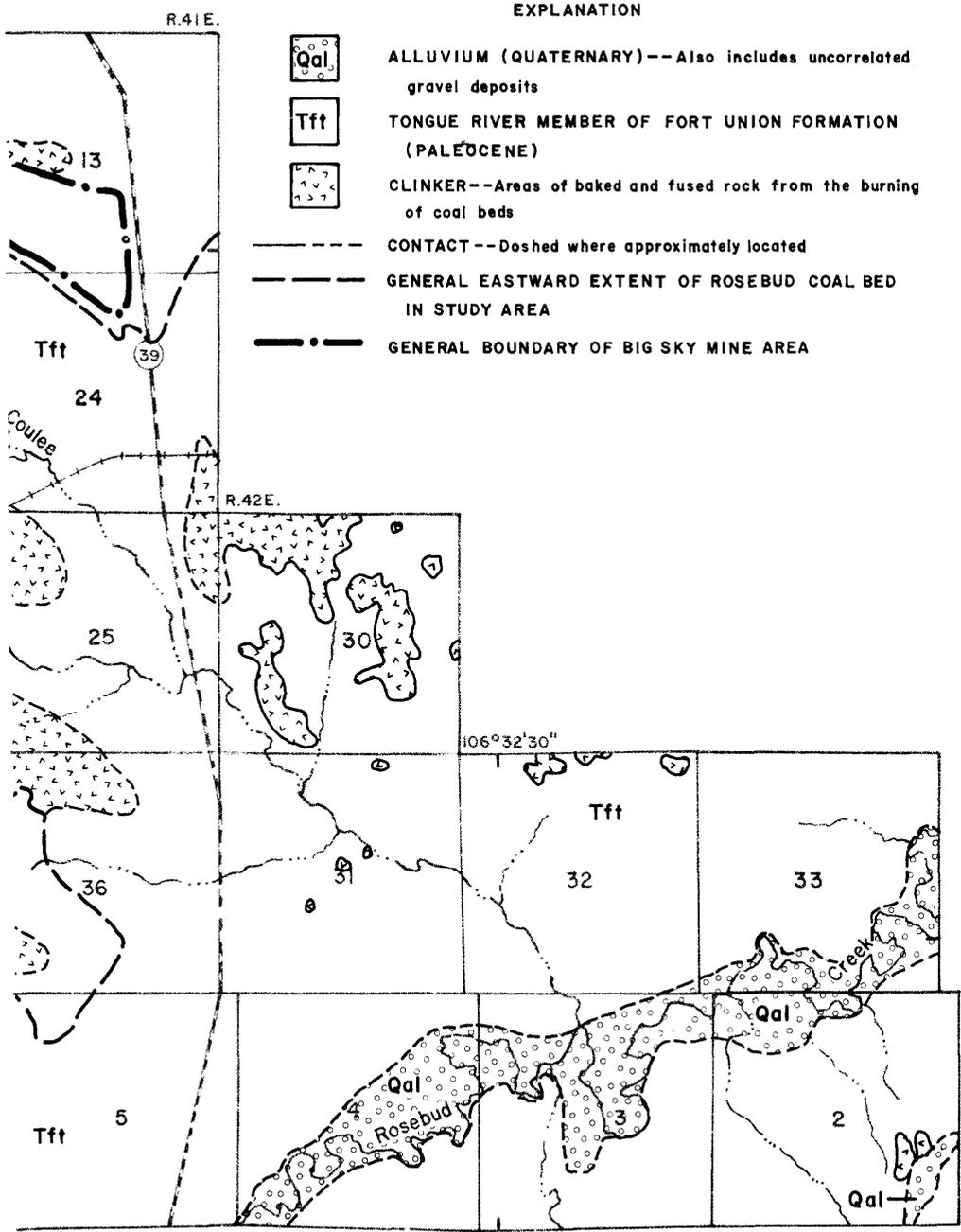
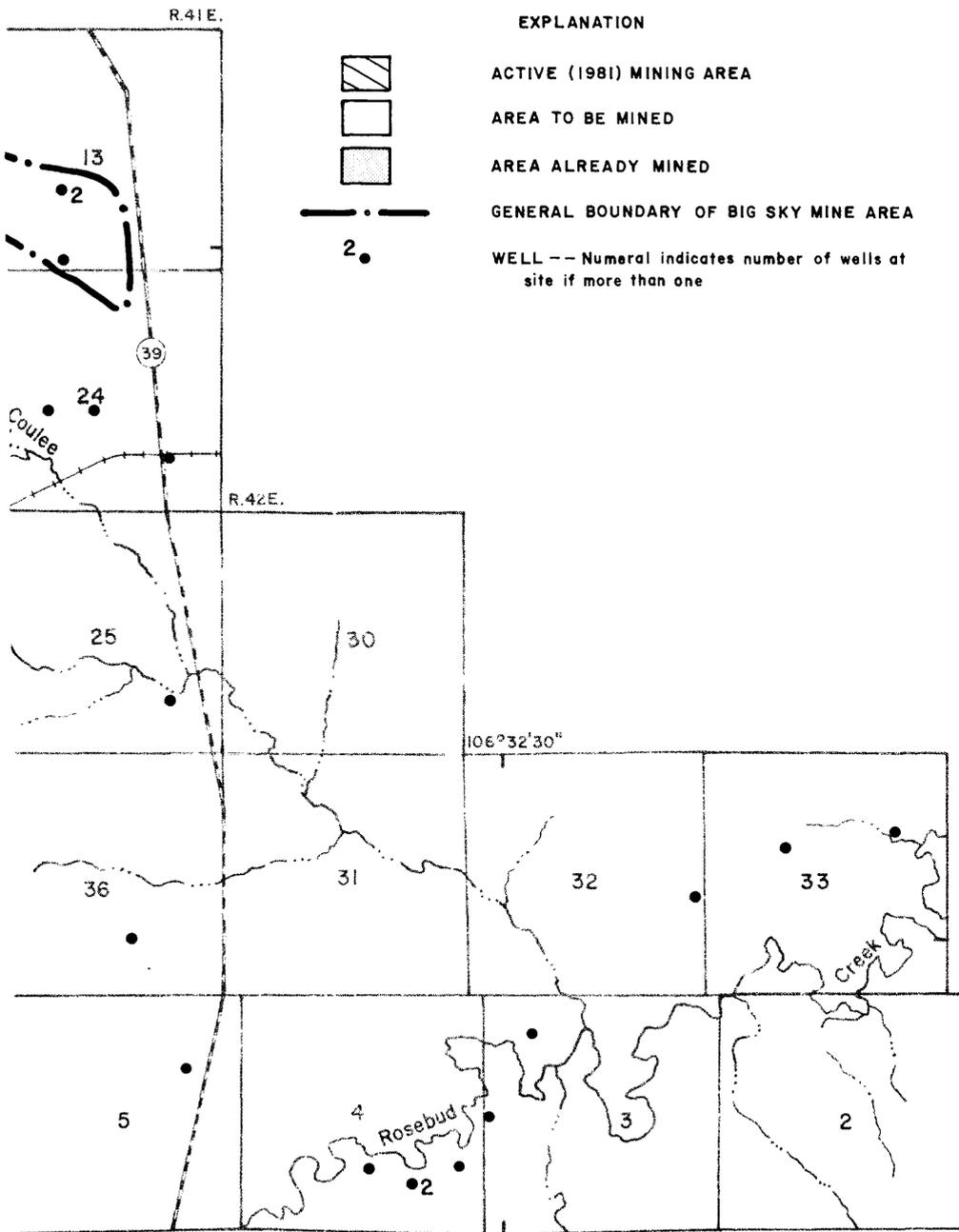


Figure 21.--Geologic map of the Big



Geology modified from Dobbin (1930), Bass (1932), and Van Voast and others (1977).
 Boundary of mine area from Peabody Coal Company, December 1981

Sky Mine study area.



Boundary of mine area from Peabody Coal Company, December 1981

wells in the study area.

The principal coal aquifers of interest in the Big Sky Mine study area are the Rosebud and McKay coal beds. The approximate altitude of the 1976 potentiometric surface of the Rosebud coal aquifer is shown in figure 23. The highest hydraulic head is generally in the northwest part of the study area and the lowest hydraulic head is near the easternmost edge of the Rosebud coal bed. The direction of flow generally is southeast. Water in the Rosebud coal aquifer can be confined or unconfined, depending on the degree of saturation and the overburden lithology. Water discharges laterally from the Rosebud coal aquifer into clinker and sandy material of the Tongue River Member, then into the alluvium, and eventually discharges to Rosebud Creek and its tributaries. Faults and fracture zones in the area are not known to either impede or enhance the flow of ground water.

Another principal aquifer of interest is the mine spoils. Owing to the sandy nature of the spoils at the Big Sky Mine, the spoils aquifer consists of both a basal rubble zone and granular material overlying the rubble zone. Water in the spoils aquifer can be unconfined or confined, depending mainly on the lithology. In most areas of the spoils aquifer, the water is unconfined. Where the water is confined, the spoils aquifer is restricted to the basal rubble zone.

Recharge

Recharge in the Big Sky Mine study area results from infiltration of precipitation. Most of the recharge occurs in areas of outcropping clinker (fig. 21) during spring snowmelt or after extended wet intervals during April, May, and June when precipitation is greatest (fig. 4). Although much of the clinker is not associated with the Rosebud and McKay coal beds, the sandy nature of much of the material between the clinker and these coals permits significant hydraulic connection. The rate of recharge probably is less than 1 inch annually.

Recharge to the mine spoils probably occurs primarily as lateral inflow from the coal aquifers. The sandy nature of the spoils probably also permits infiltration of precipitation.

Discharge

Discharge from the Rosebud and McKay coal aquifers is by lateral flow to the contiguous clinker and sand aquifer to the southeast, which eventually discharges to Rosebud Creek, and by pumpage from wells used for domestic and stock-watering purposes. Pumpage from the coal aquifers for domestic and stock use is small. In most areas the hydraulic head in the McKay coal bed is lower than the hydraulic head in the Rosebud, allowing downward leakage from the Rosebud to the McKay. The magnitude of the vertical leakage probably is relatively small as a result of the small vertical hydraulic conductivity of the interburden. Evapotranspiration from the clinker and sand aquifer and from alluvium occurs in topographically low areas of Emile Coulee, Miller Coulee, Lee Coulee, and Rosebud Creek (fig. 23), where water levels are near the surface. The annual evapotranspiration is probably about the same as the potential annual evapotranspiration of 40 inches.

Discharge from the spoils aquifer probably will be by lateral outflow to the clinker and sand aquifer to the southeast. However, significant discharge probably will not occur until mining is completed. Evapotranspiration may also occur in topographically low areas of the spoils.

Hydraulic conductivity and transmissivity

Aquifer tests were conducted by the Montana Bureau of Mines and Geology as parts of previous studies of aquifers in the area (Van Voast and others, 1978, p. 21 and 82). The results of nine aquifer tests on coal aquifers in and near the Big Sky Mine indicate a range in hydraulic conductivity of 0.07 to 68 ft/d, with an average of 8.8 ft/d and a median of 0.79 ft/d. The transmissivity determined from these tests ranged from 0.65 to 1,700 ft²/d, with an average of 210 ft²/d and a median of 7.5 ft²/d. The results of eight aquifer tests on the spoils aquifer at the Big Sky Mine indicate a range in hydraulic conductivity from 0.0010 to 65 ft/d, with an average of 9.7 ft/d and a median of 0.028 ft/d. The transmissivity determined from these tests ranged from 0.032 to 3,100 ft²/d, with an average of 560 ft²/d and a median of 0.75 ft²/d.

The hydraulic conductivity of the coal aquifers is due primarily to cleat and probably is anisotropic. The orientations of the cleat probably are similar to those in the Decker area, or generally northeast and northwest. The direction of maximum hydraulic conductivity probably is northwest, perpendicular to the strike. The aquifer tests conducted by the Montana Bureau of Mines and Geology were not designed to determine anisotropy.

Effective porosity

Two recirculating injection-withdrawal tracer tests were conducted to determine the effective porosity of the Rosebud coal bed and of the Big Sky Mine spoils. The tests were conducted using wells 01N41E21DBDB01 and 01N41E21DBDB02 that were completed in the Rosebud coal bed and wells 01N41E22CCAD01 and 01N41E22CCAD02 that were completed in the spoils (table 8). The following conditions were in effect during the tests:

	<u>Rosebud coal</u>	<u>Mine spoils</u>
Distance between wells (feet)	16.05	19.70
Withdrawal rate (cubic feet per minute)	0.18	1.75
Injectant concentration (Molar)	0.146	0.0135
Time of injection (minutes)	26	32
Aquifer thickness (feet)	25	15

The theoretical and observed tracer-concentration breakthrough curves are compared in figures 24 and 25. The theoretical curves were not calculated beyond the time corresponding to the beginning of the second recirculation of the tracer, owing to limitations of the analyzing program from which they were produced (Grove, 1971). For the Rosebud coal aquifer, the theoretical curve produced by using an effective porosity of 3.5 percent and a dispersion constant of 35 feet most closely matched the observed curve (fig. 24). For the mine-spoils aquifer, the theoretical curve produced by using an effective porosity of 8.0 percent and a dispersion constant of 20 feet most closely matched the observed curve (fig. 25).

The sensitivity of the analyzing procedure is shown in figures 26 through 29. An increase in effective porosity decreased the magnitude of the peak of the curve, whereas a decrease in effective porosity increased the magnitude of the peak. An

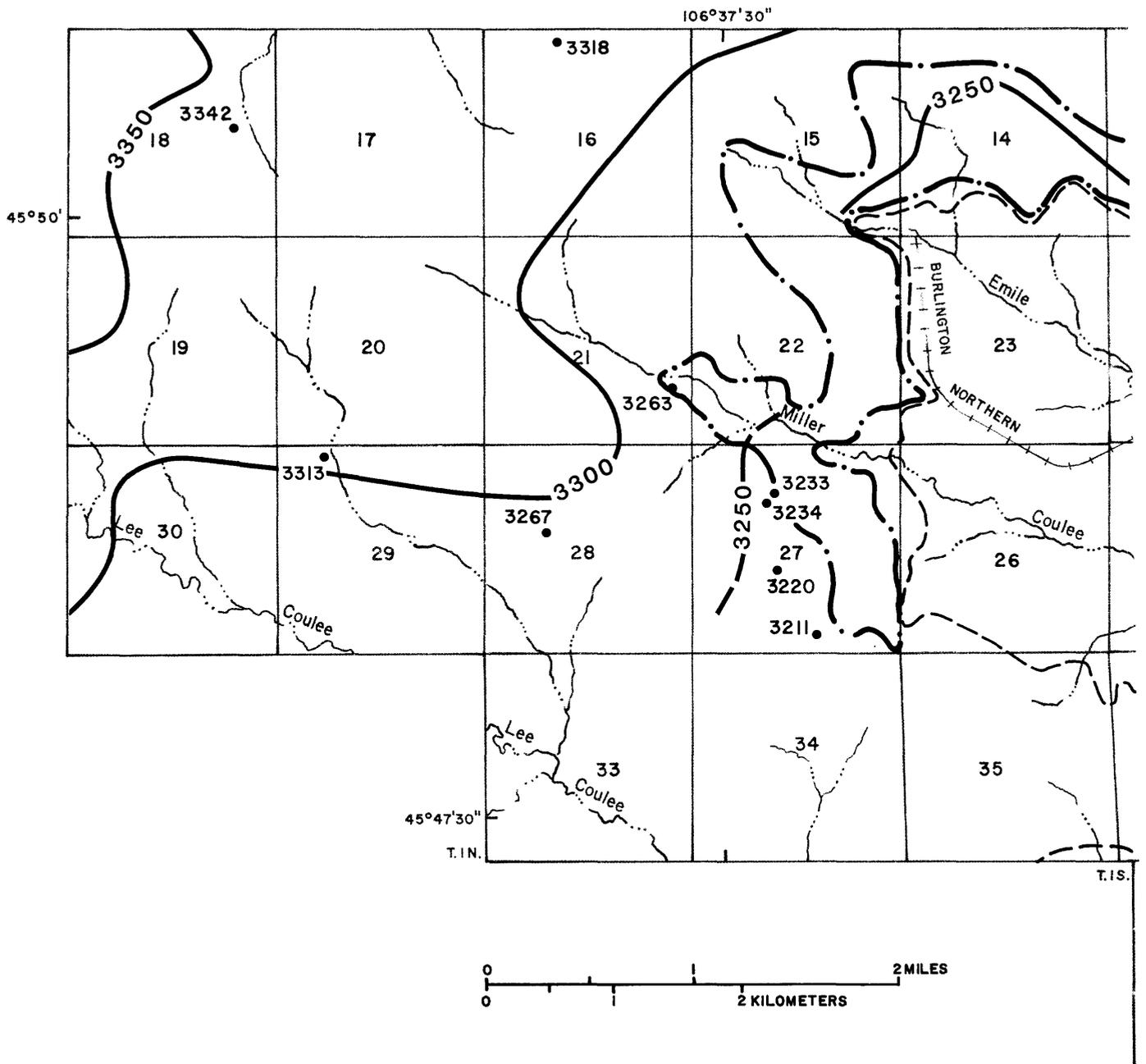
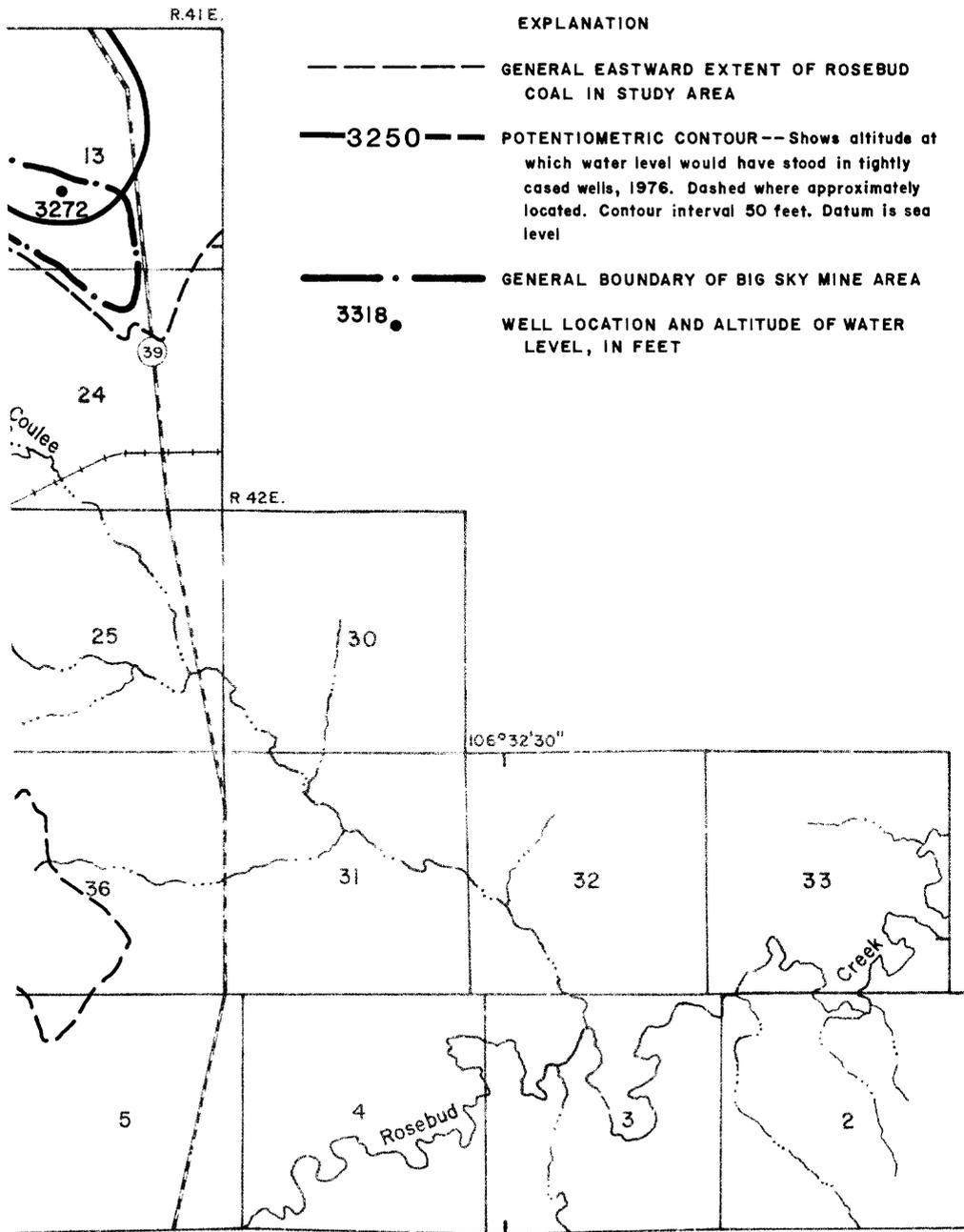


Figure 23.--Potentiometric surface of water in the



Hydrology modified from Van Voast and others (1977, plate 5). Boundary of mine area from Peabody Coal Company, December 1981

Rosebud coal bed, Big Sky Mine study area.

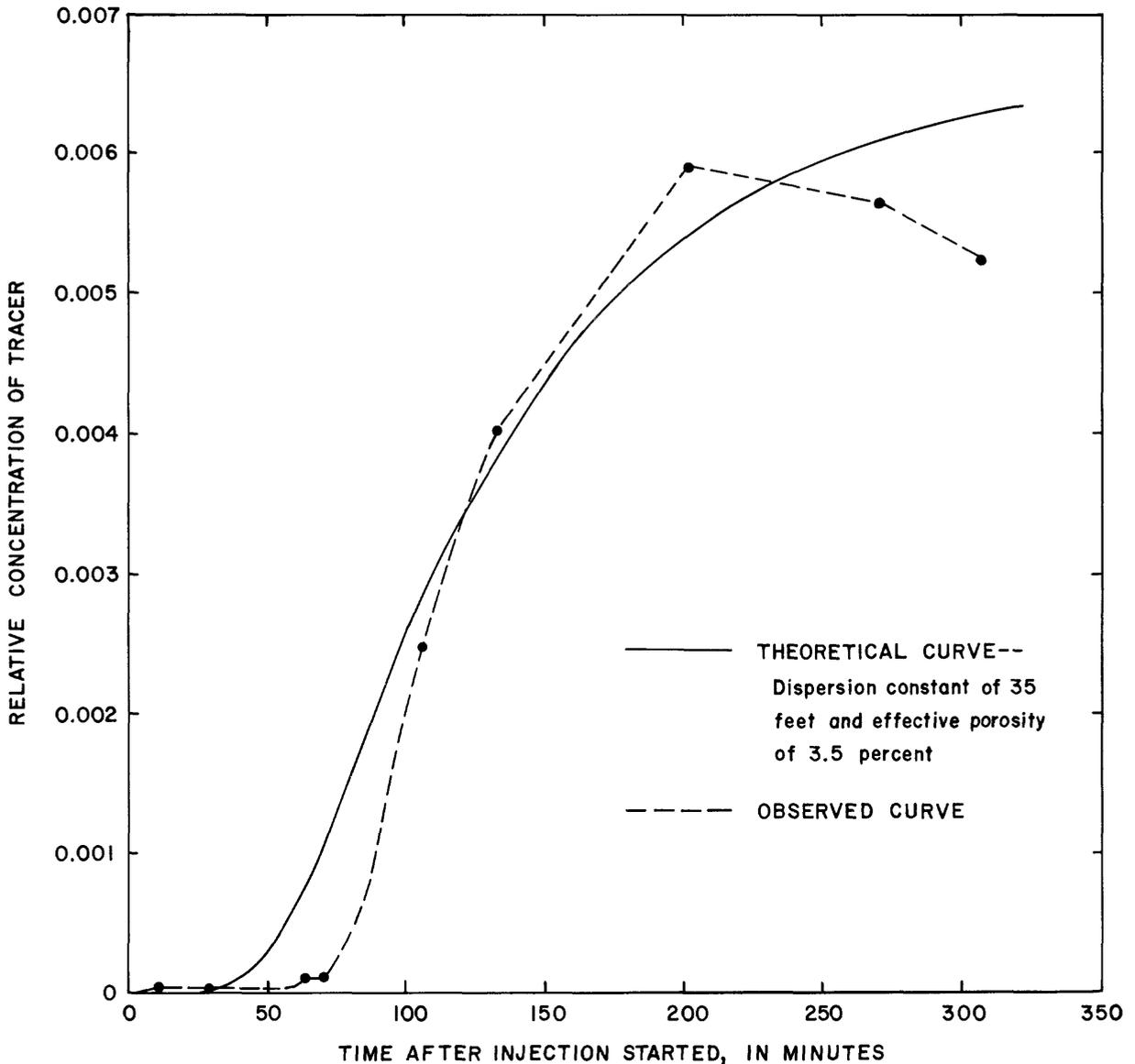


Figure 24.--Theoretical and observed breakthrough curves for injection-withdrawal tracer test, Rosebud coal bed, Big Sky Mine area.

increase in the dispersion constant tended to move the curve to the left, and a decrease in the dispersion constant tended to move the curve to the right.

Based on the relatively close spacing of the wells tested, the dispersion constants determined from the test analyses probably are not representative of the aquifers as a whole. Also, because only one test was conducted for each aquifer and because the area of influence of each test is only a small part of each aquifer, the results of the tests probably indicate only the general magnitude of the effective porosity. Because of the test method, the determined effective porosity may represent only the fracture effective porosity of a dual-porosity system.

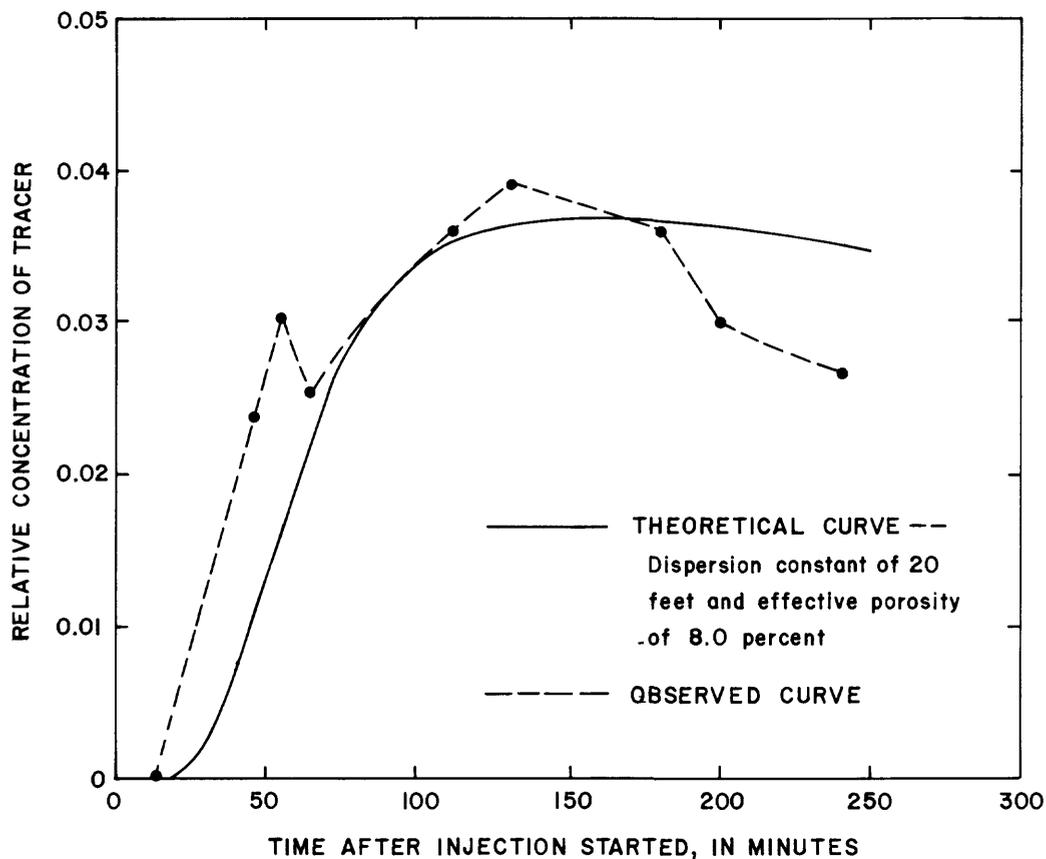


Figure 25.--Theoretical and observed breakthrough curves for injection-withdrawal tracer test, Big Sky Mine spoils.

Geochemistry

Existing water quality and geochemical processes

Water in the coal aquifers in the Big Sky Mine area has an average dissolved-solids concentration of about 2,700 mg/L and is primarily a calcium magnesium sulfate type. The percentage of total milliequivalents per liter for the major ions as determined from the most recent and representative analyses in table 9 is shown in figure 30.

Water in the spoils aquifer has an average dissolved-solids concentration of about 3,700 mg/L. The spoils water also is mainly a calcium magnesium sulfate type (fig. 30).

The equilibrium relationships, determined using the program WATEQF, between water from selected wells completed in the coal aquifers and selected mineral species are given in table 11. Saturation indices indicate that water from the coal aquifers generally is saturated or supersaturated with respect to quartz, calcite, aragonite, dolomite, magnesite, and albite. Two of the samples are almost saturated with respect to gypsum.

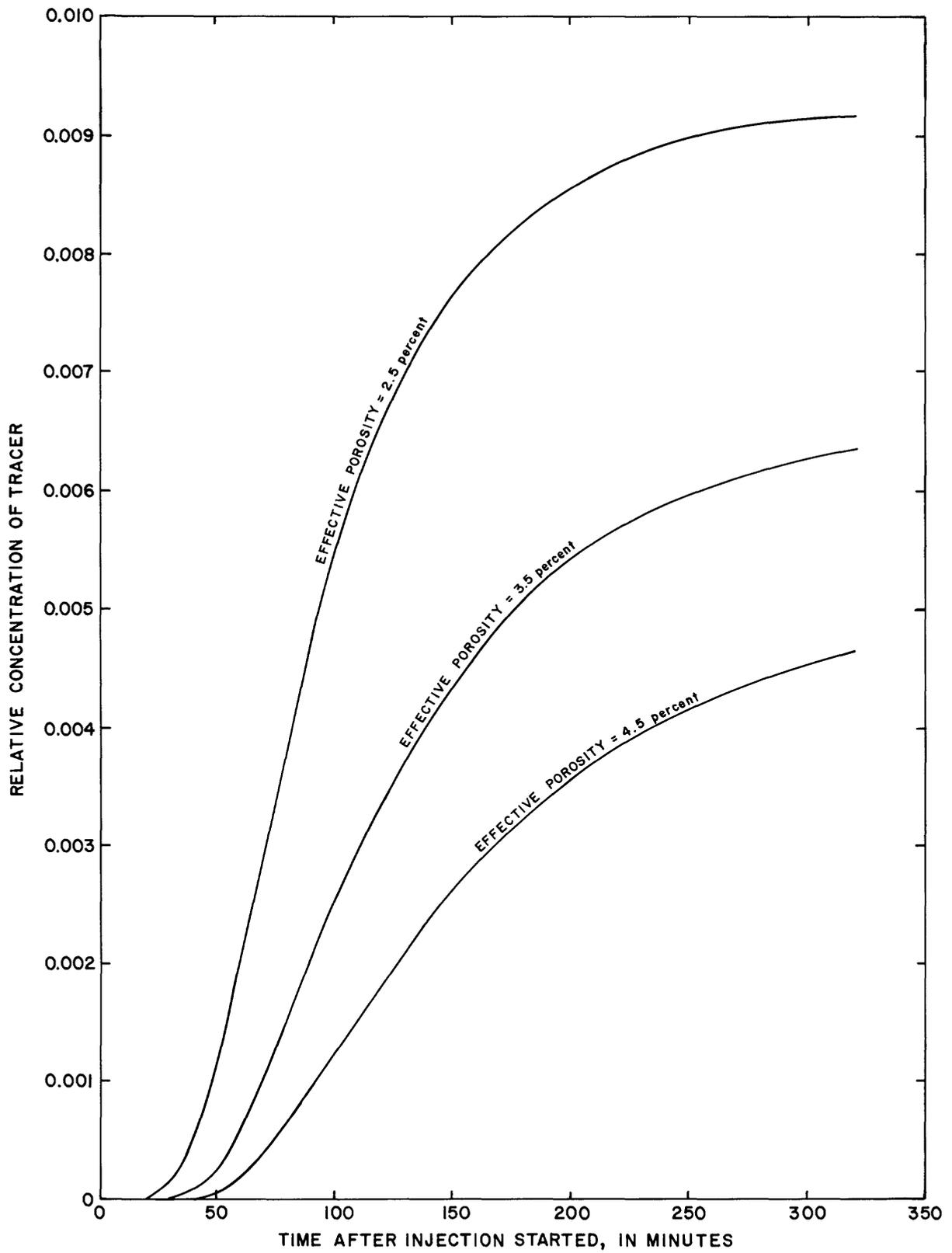


Figure 26.--Theoretical breakthrough curves for various values of effective porosity with a dispersion constant of 35 feet, Rosebud coal bed, Big Sky Mine area.

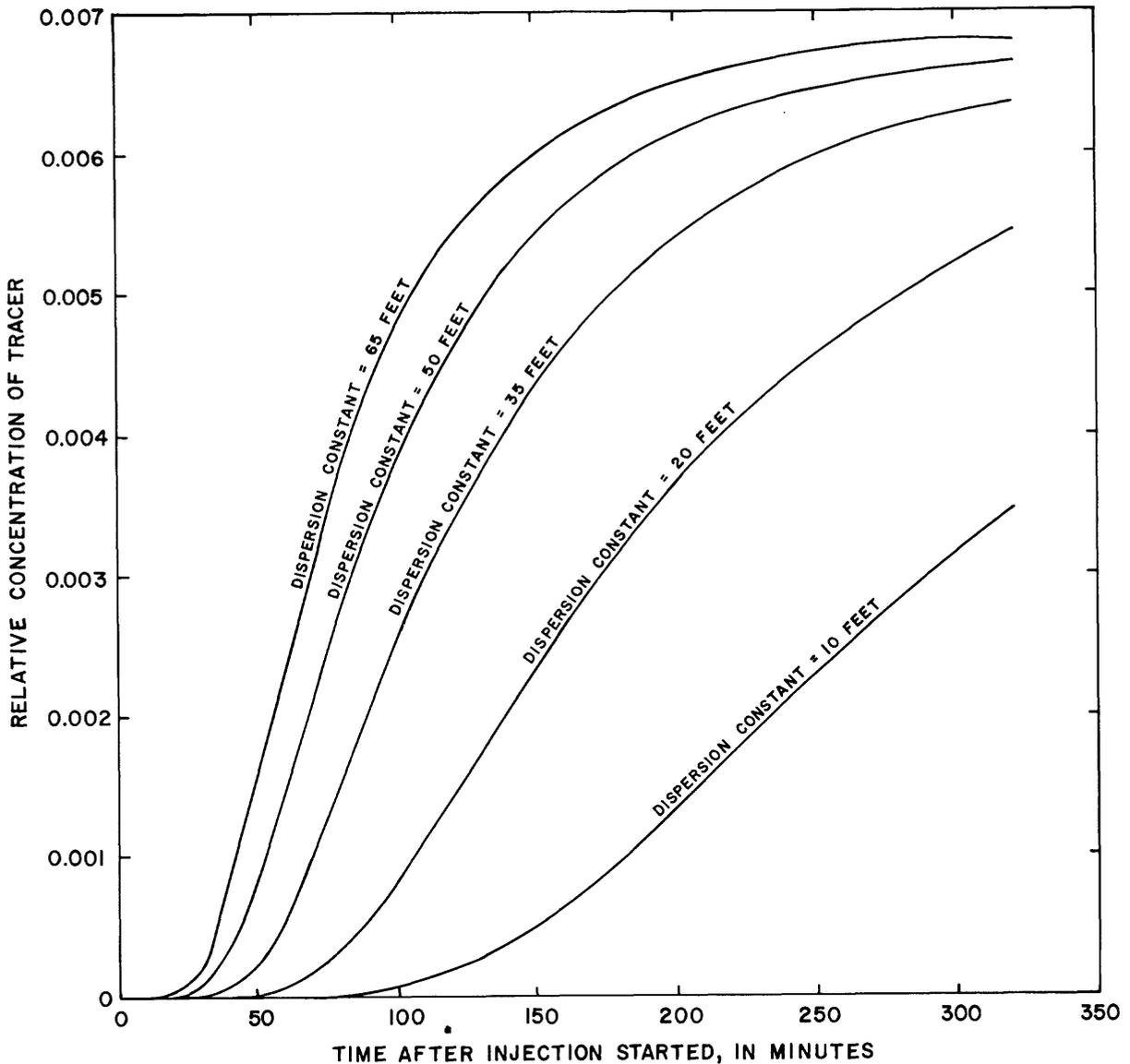


Figure 27.--Theoretical breakthrough curves for various values of dispersion constant with an effective porosity of 3.5 percent, Rosebud coal bed, Big Sky Mine area.

The equilibrium relationships between water from selected wells completed in the spoils aquifer and selected mineral species are given in table 12. The relationships are similar to those of water from the coal aquifers, except that three of the samples showed saturation or supersaturation with respect to gypsum. The similarities indicate that water in the coal aquifers has had at least some contact with the clastic facies of the Tongue River Member. The state of saturation with respect to gypsum indicates that the source of some of the water in the coal probably is recharge by surface infiltration and downward movement through the overburden.

The general state of saturation or supersaturation of water from the spoils aquifer denotes that the dissolved-solids concentration is near maximum. The

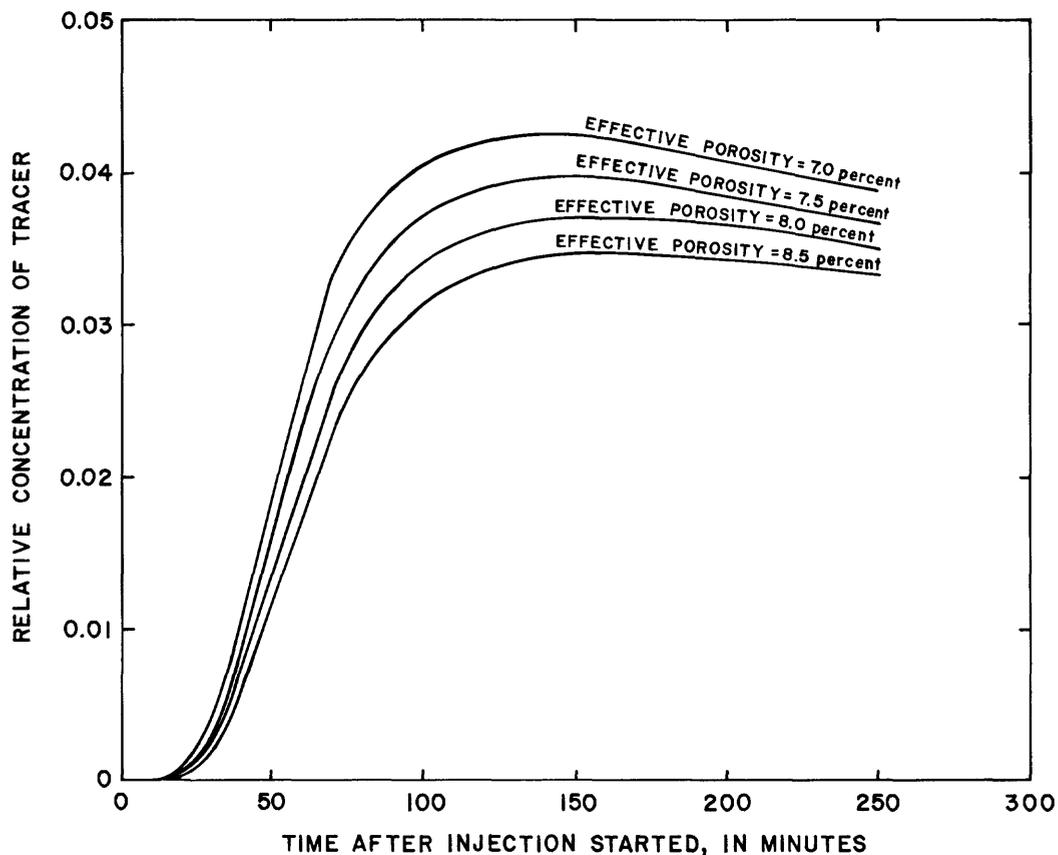


Figure 28.--Theoretical breakthrough curves for various values of effective porosity with a dispersion constant of 20 feet, Big Sky Mine spoils.

concentration will not increase significantly, assuming no change in temperature or solute sources.

The geochemical processes that determine the quality of water in the coal aquifers are primarily the dissolution of quartz, calcium and magnesium carbonates, calcium sulfate, and possibly magnesium sulfate by surface-recharge waters throughout the study area. Owing to the lack of sodic clay in the overburden, the exchange of calcium and magnesium for sodium is not predominant, although minerals from which the clays could be formed apparently are present. Sulfate-reducing bacteria probably decrease the concentration of sulfate (Dockins and others, 1980), but this process apparently is not predominant either.

Projection of future water quality

Batch-mixing experiments were conducted to determine ground-water-quality changes that might result from mining. Water from the Rosebud coal bed was mixed with spoils material from Miller Coulee and with spoils material from Emile Coulee to try to simulate previously observed changes in water quality. Water from spoils in Miller Coulee was mixed with the Rosebud coal and with the McKay coal to determine possible changes in quality if water from the spoils flows through a coal aquifer.

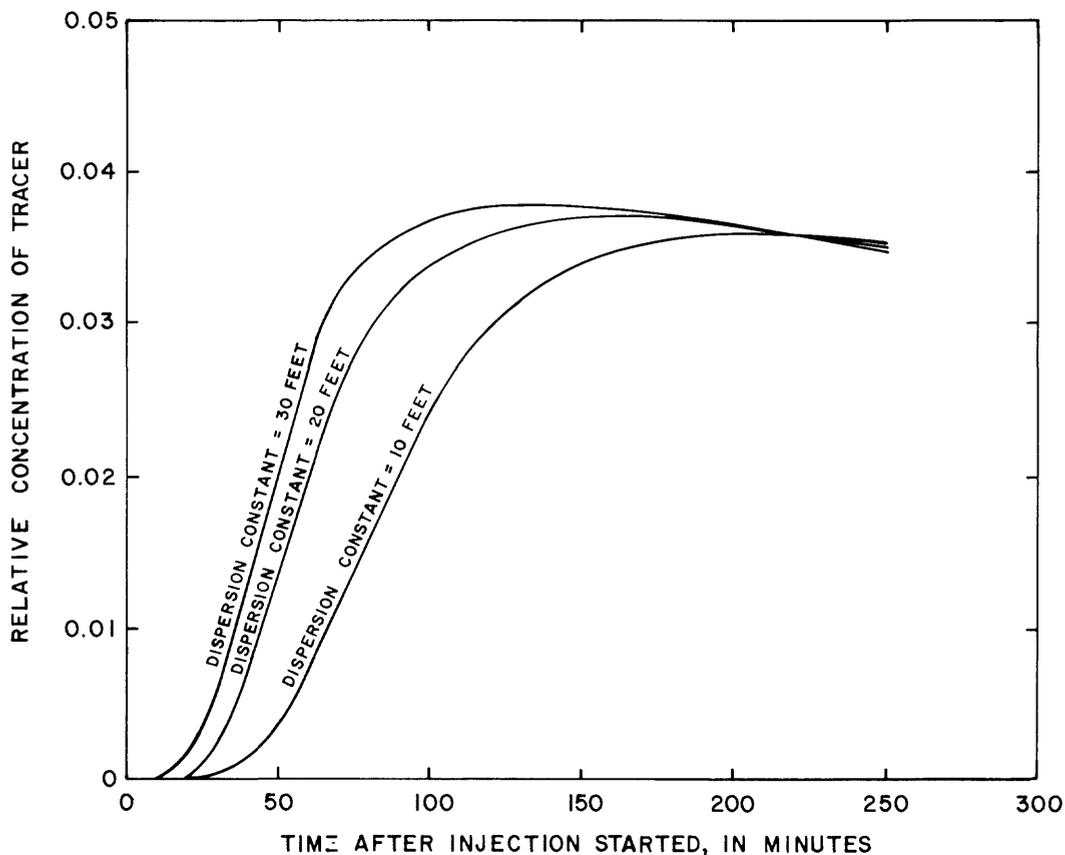


Figure 29.--Theoretical breakthrough curves for various values of dispersion constant with an effective porosity of 8.0 percent, Big Sky Mine spoils.

The resulting differences in pH and dissolved solids between the pre-mixing, or control, water samples and the post-mixing water samples are shown graphically in figure 31. In general, water from the coal aquifer mixed in a 2:1 ratio, by weight, with spoils material showed little or no change in pH. Dissolved-solids concentration increased about 400 mg/L using spoils material from Miller Coulee and about 1,600 mg/L using spoils material from Emile Coulee (table 13). These increases are similar to increases observed at some wells. The mixtures of a 5:1 ratio showed lesser increases, indicating that the amount of soluble material was the limiting factor.

In comparison to the control samples, the mixtures of coal-aquifer water with Miller Coulee spoils material showed general increases in the concentrations of calcium, potassium, sulfate, copper, lead, molybdenum, silver, titanium, vanadium, and zirconium (tables 13 and 14). The same mixtures showed general decreases in the concentrations of bicarbonate, chloride, manganese, strontium, and zinc. The mixtures of coal-aquifer water with Emile Coulee spoils material showed general increases in concentrations of calcium, magnesium, sodium, potassium, sulfate, chloride, and boron, and general decreases in the concentrations of bicarbonate, manganese, molybdenum, silver, and zinc.

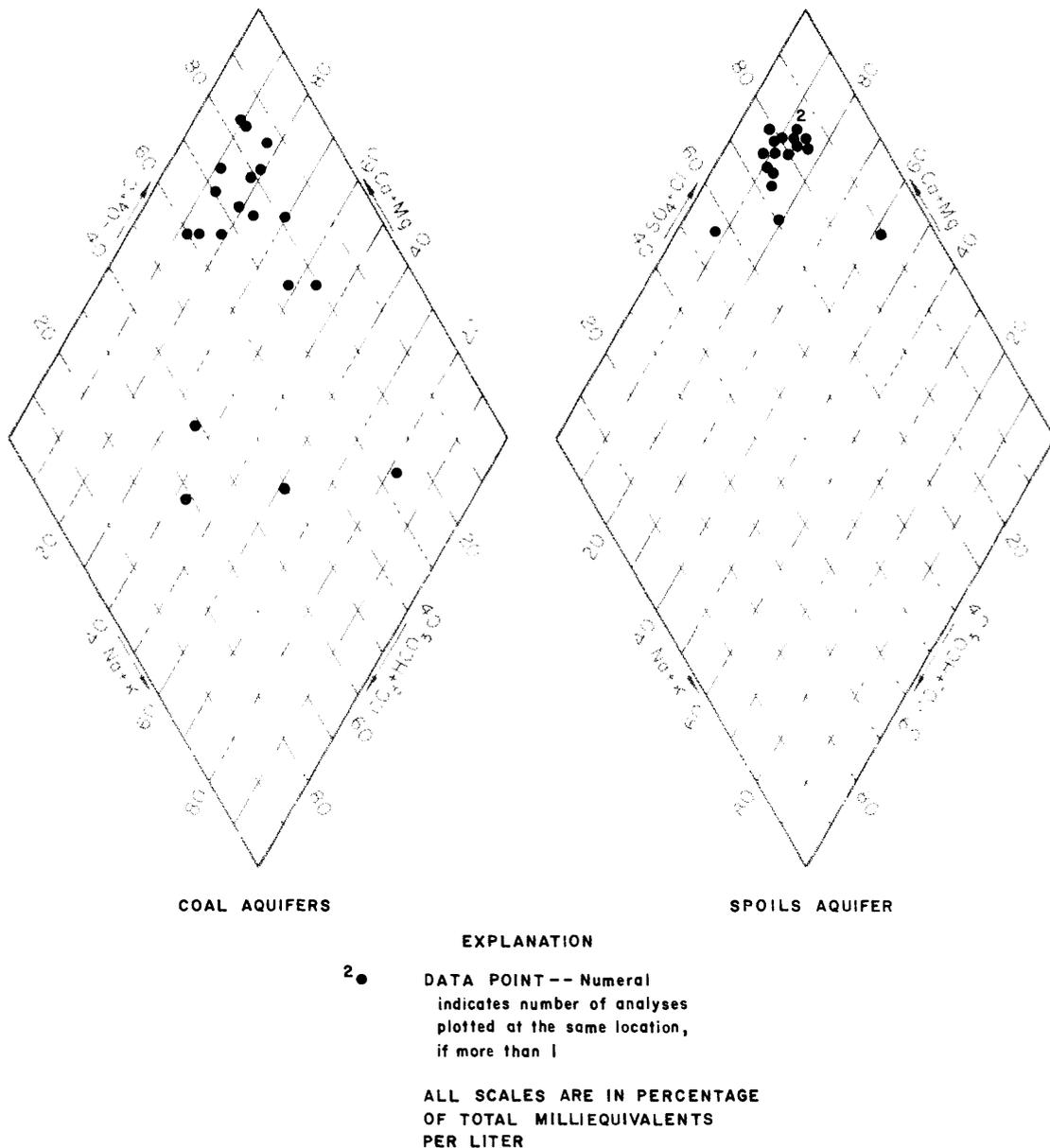


Figure 30.--Water-analysis diagrams for water from wells, Big Sky Mine study area.

The amount of water in a 2:1 mixture of water and spoils material represents about 44 effective pore volumes, based on a specific gravity of 1.75 for the spoils material and an effective porosity of 8.0 percent. Similarly, the amount of water in a 5:1 mixture represents about 110 effective pore volumes.

The average velocity of water through the spoils is estimated to be 1.2 ft/d, based on a post-mining gradient similar to the 1976 gradient of about 50 ft/mi, a hydraulic conductivity of 10 ft/d, and an effective porosity of 8.0 percent. If the average width of the spoils is about one-third mile, then about 1,500 days (about 4 years) will be required for water moving at the average velocity to flow through the spoils. The passage of 44 effective pore volumes would take about 180

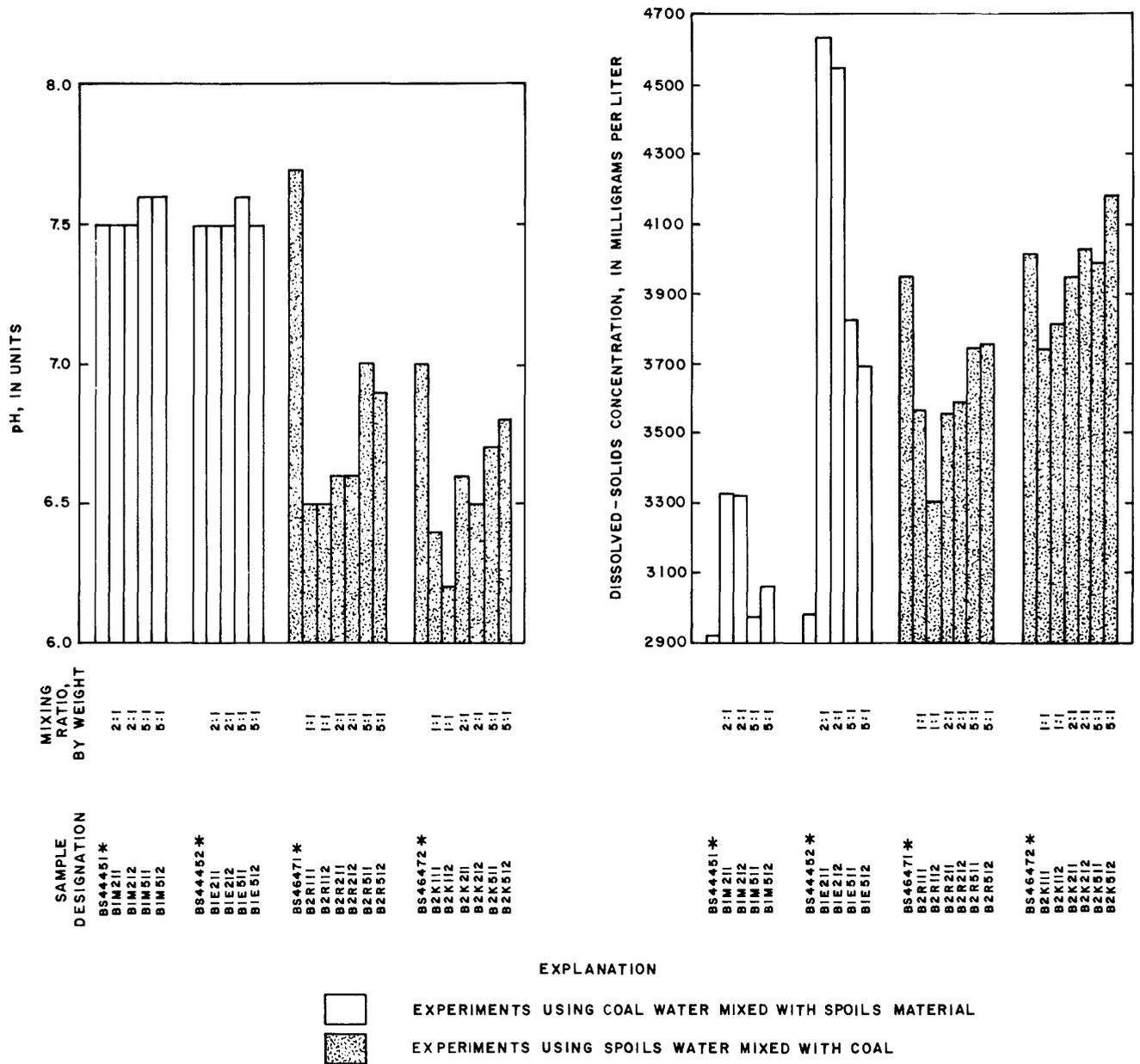


Figure 31.--Changes in pH and dissolved-solids concentration resulting from batch-mixing experiments using materials from the Big Sky Mine study area. The asterisks designate the control samples.

years, and the passage of 110 effective pore volumes would require about 440 years. Therefore, any decrease in the dissolved-solids concentration in the spoils water due to the limiting factor of soluble material in the spoils probably will not occur in the near future.

In comparison to the control samples, mixtures of water from Miller Coulee spoils with coal showed a decrease in pH (generally within 1 pH unit) and a decrease in dissolved-solids concentration of several hundred milligrams per liter. Mixtures with Rosebud coal showed general increases in concentrations of fluoride,

aluminum, boron, cadmium, chromium, manganese, and molybdenum, and general decreases in the concentrations of calcium, sodium, potassium, bicarbonate, chloride, and strontium. Mixtures with the McKay coal showed general increases in the concentrations of sodium, fluoride, aluminum, boron, cadmium, chromium, iron, lead, manganese, silver, and titanium, and general decreases in concentrations of magnesium, potassium, bicarbonate, and chloride. For both coal mixtures, the sulfate concentration remained essentially unchanged.

The processes by which the changes occur are not known. Possible processes are ion exchange with the coal or chemical reaction with impurities in the coal. Another possibility is dilution of the mixing water by water held within the coal. Although the coal used in the experiments was air dried, analyses show that moisture content of the Rosebud and McKay coals ranges from about 20 to 25 percent (Matson and Blumer, 1973, p. 78). If further experiments are conducted, it would be important to discern which processes predominate. However, if the laboratory experiments conducted for this study are representative of possible future conditions and the observed changes are a real phenomenon, then the dissolved-solids concentration may decrease several hundred milligrams per liter if water from the spoils flows through a coal aquifer. Also, the changes may be different depending on the coal bed.

The amount of water represented by a 1:1 mixture of water and coal is about 40 effective pore volumes, based on a specific gravity of coal of 1.30 and an effective porosity of the coal of 3.5 percent. The amount of water in a 2:1 mixture represents about 70 effective pore volumes, and a mixture of 5:1 represents almost 190 effective pore volumes.

Effects of mining

The post-mining equilibrium flow system in the Big Sky Mine study area probably will closely resemble the pre-mining system as a result of the similarities in hydraulic properties of the coal and the spoils. Between the mine area and Rosebud Creek--the main area of discharge--the aquifers consist of clinker, a relatively sandy facies of the Tongue River Member, and alluvium. These aquifers probably have hydraulic properties similar to the spoils. The average velocity of water moving from the spoils to Rosebud Creek is estimated to be 1.2 ft/d, based on a gradient of 50 ft/mi, a hydraulic conductivity of 10 ft/d, and an effective porosity of 8.0 percent. The distance from the spoils to Rosebud Creek ranges from 3 to 5 miles. Therefore, 36 to 60 years will be required for water moving at the average velocity to flow from the southeastern edge of the spoils to Rosebud Creek.

At post-mining equilibrium, the quantity of water flowing from the spoils to Rosebud Creek will be about 1.0 ft³/s, based on a transmissivity of 560 ft²/d, a gradient of 50 ft/mi, and a width of 3 miles. If the average dissolved-solids concentration is 1,000 mg/L greater than for pre-mining conditions, the increase in dissolved-solids contribution to Rosebud Creek will be about 980 tons per year. The average annual dissolved-solids load in Rosebud Creek is 50,500 tons per year based on an average annual discharge of 59.0 ft³/s and an average dissolved-solids concentration of 870 mg/L (U.S. Geological Survey, 1981, p. 411 and 412). Therefore, the mining activity probably will increase the average annual dissolved-solids load in Rosebud Creek by about 2 percent. However, more pronounced effects may occur during July, August, and September when flow in Rosebud Creek generally is less than 10 ft³/s (U.S. Geological Survey, 1981, p. 411).

SUMMARY

Surface geology in the study areas consists predominantly of material within the Tongue River Member of the Paleocene Fort Union Formation. The lithology is mostly shale, siltstone, sand, sandstone, coal, and clinker.

Coal aquifers in the West Decker Mine study area consist of combinations of the Anderson, Dietz 1, and Dietz 2 coal beds, which have a combined thickness of about 80 feet. Surface recharge from infiltration of precipitation is estimated to be less than 1 inch per year and probably occurs mainly in areas of clinker and alluvium. Discharge is mainly through clinker and alluvium to the Tongue River Reservoir. The coal aquifers have an average hydraulic conductivity of 5.2 ft/d, a median hydraulic conductivity of 2.2 ft/d, and an effective porosity of at least 0.3 percent. Water in the coal aquifers has an average dissolved-solids concentration of about 1,400 mg/L and is primarily a sodium bicarbonate type.

The spoils aquifer in the West Decker Mine area consists primarily of the rubble zone at the base of the spoils and generally is confined. Recharge primarily occurs as lateral flow from the Anderson-Dietz 1 coal aquifer. Discharge after mining is completed will be through clinker and alluvium east of the spoils and eventually to the Tongue River Reservoir. The spoils aquifer has an average hydraulic conductivity of 2.8 ft/d, a median hydraulic conductivity of 1.8 ft/d, and an effective porosity of 0.4 percent. Water in the spoils has an average dissolved-solids concentration of about 2,500 mg/L and is a sodium bicarbonate type. Assuming no change in temperature or solute sources, the dissolved-solids concentration in the spoils water will not increase significantly in the future.

Batch-mixing experiments simulating chemical changes observed in the field indicate that soluble material in the West Decker Mine spoils will not be a limiting factor of the quality of water in spoils in the near future. The experiments also indicate that if the spoils water flows through a coal aquifer, the dissolved-solids concentration may decrease by several hundred milligrams per liter.

At post-mining equilibrium, water levels west of the West Decker Mine probably will increase almost 12 feet over pre-mining levels, although the increases diminish within several miles of the mine. Approximately 13 years will be required for water moving at an average velocity of 2 ft/d to flow from the spoils to the Tongue River Reservoir. Water discharge from the spoils to the reservoir will be about 0.065 ft³/s. The increase in dissolved-solids contribution to the reservoir due to mining will be less than 1 percent.

Coal aquifers in the Tongue River Member in the Big Sky Mine study area consist of the Rosebud coal, which is about 25 feet thick, and the underlying McKay coal, which is about 10 feet thick. Recharge from infiltration of precipitation is estimated to be less than 1 inch per year and probably occurs throughout the study area owing to extensive areas of clinker and the sandy nature of the overburden. Discharge from both aquifers is primarily to the contiguous clinker and sand aquifer to the southeast, which eventually discharges to Rosebud Creek. The coal aquifers have an average hydraulic conductivity of 8.8 ft/d, a median hydraulic conductivity of 0.79 ft/d, and an effective porosity of about 3.5 percent. Water in the coal aquifers has an average dissolved-solids concentration of about 2,700 mg/L and is a calcium magnesium sulfate type.

The spoils aquifer in the Big Sky Mine area consists of both a basal rubble zone and granular material overlying the rubble zone. Recharge is by lateral flow from the coal aquifers and by infiltration of precipitation. Discharge after mining is completed will be primarily by lateral outflow. The spoils aquifer has an average hydraulic conductivity of 9.7 ft/d, a median hydraulic conductivity of 0.028 ft/d, and an effective porosity of 8.0 percent. Water in the spoils has an average dissolved-solids concentration of about 3,700 mg/L and is a calcium magnesium sulfate type. Assuming no change in temperature or solute source, the dissolved-solids concentration in the spoils water will not increase significantly in the future.

Batch-mixing experiments simulated a range of chemical changes that encompass changes observed in the field and indicate that any decrease in the dissolved-solids concentration of water in the Big Sky Mine spoils due to flushing of soluble material probably will not occur in the near future. The experiments also indicate that if the spoils water flows through a coal aquifer, the dissolved-solids concentration may decrease by several hundred milligrams per liter.

At post-mining equilibrium, water levels near the Big Sky Mine probably will closely resemble pre-mining levels. Approximately 36 to 60 years will be required for water moving at an average velocity of 1.2 ft/d to flow from the spoils to Rosebud Creek. Ground-water discharge to the creek will be about 1.0 ft³/s. The average annual increase in dissolved-solids contribution to the creek will be about 2 percent, although a greater percentage increase may occur during the summer months when flow in Rosebud Creek is diminished.

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DATA

Table 1.--Records of selected wells in the West Decker Mine study area

[Well number: Numbering system described in text.
 Site identification number: Unique number consisting
 of latitude, longitude, and sequence number for the
 site.
 Altitude of land surface: In feet above sea level.
 Geohydrologic unit: Tft, Tongue River Member of
 Fort Union Formation; Sp, spoils at West Decker
 Mine.]

Aquifer zone: Cl, clinker associated with unit in paren-
 theses; A, Anderson coal bed; Dz2, Dietz 2 coal bed; C,
 Canyon coal bed; A-Dz1, combined Anderson-Dietz 1 coal
 bed; A-Dz1-Dz2, combined Anderson-Dietz 1-Dietz 2 coal
 bed; Dz1-Dz2, combined Dietz 1-Dietz 2 coal bed; O,
 overburden superjacent to unit in parentheses; I, inter-
 burden between the units in parentheses.
 Source of data: BM, Montana Bureau of Mines and Geology;
 GS, U.S. Geological Survey]

Well number	Site identification number	Other well desig- nation	Altitude of land surface (feet)	Depth of well below land surface (feet)	Geo- hydro- logic unit	Aquifer zone	Depth to water below land surface (feet)	Date water level measured (month-day- year)	Source of data
08S39E25DBDD01	450600106533701	---	3,768	39	Tft	A-Dz1-Dz2	10.3	07-14-74	GS
08S40E26ACBC02	450623106473801	DN-7B	3,460	27	Tft	A-Dz1 and Cl(A-Dz1)	26.47	01-11-81	GS
08S40E26CCCB01	450551106482201	WRN-01	3,463	30	Tft	Dz2	28.23 28.43 Dry 28.51 28.58 29.25	03-03-75 06-04-75 12-12-76 04-17-78 05-16-78 03-26-81	BM
08S40E33AACB01	450538106482201	WRN-02	3,493	88	Tft	Dz2	54.33 54.69 54.47 53.12 53.84 52.87	01-06-75 05-01-75 06-04-75 06-08-77 04-17-78 03-26-81	BM
08S40E33AACB02	450538106495401	WRN-03	3,491	59	Tft	Cl(A-Dz1)	53.73 53.58 53.63 57.28 53.64 54.95	01-06-75 04-04-75 06-04-75 11-17-76 04-17-78 03-26-81	BM
08S40E33ACDB01	450525106503600	---	3,485	--	Tft	Dz2	54.79	10-11-73	GS, BM
08S40E33CABB01	450520106503001	WRN-04	3,492	39	Tft	A-Dz1	13.39 12.35 10.33 11.20	01-06-75 06-04-75 04-17-78 03-26-81	BM
08S40E33CADA01	450511106501901	WRN-05	3,475	85	Tft	Dz2	15.29 14.86 15.81 14.83 14.35	01-06-75 06-04-75 11-18-76 04-17-78 03-26-81	BM
08S40E33CADA02	450511106502101	WRN-06	3,476	48	Tft	A-Dz1	10.50 9.80 11.02 9.45 10.33 10.34	01-06-75 06-04-75 08-13-76 02-23-77 04-17-78 03-26-81	BM
08S40E33CADC01	450511106502102	WRN-07	3,482	49	Tft	A-Dz1	10.30 8.92 9.62 12.50 8.78 9.68	01-06-75 03-04-75 06-04-75 08-13-76 04-17-78 03-26-81	BM
08S40E34BDAA01	450532106490601	---	3,460	53	Tft	Cl(A-Dz1)	32.64	10-11-73	GS, BM
08S40E34DBAD01	450516106484701	WRN-08	3,424	50	Tft	Dz2	11.42 7.13 12.76 0.89 8.37 16.37	01-06-75 06-04-75 10-11-75 06-08-77 04-07-78 03-26-81	BM
08S40E34DBDA02	450511106484702	WRN-9A	3,424	129	Tft	I(Dz2--C)	3.76 2.85 7.91 15.76	01-06-75 06-04-75 04-17-78 03-26-81	BM
09S39E01BCBA01	450439106542301	WR-62	3,961	465	Tft	A-Dz1-Dz2	425.40	08-04-81	GS
09S39E14BDAD01	450255106551201	---	3,655	300	Tft	A-Dz1-Dz2	--	10-17-73	GS

Table 1.--Records of selected wells in the West Decker Mine study area--Continued

Well number	Site identification number	Other well designation	Altitude of land surface (feet)	Depth of well below land surface (feet)	Geo-hydro-logic unit	Aquifer zone	Depth to water below land surface (feet)	Date water level measured (month-day-year)	Source of data
09S39E14DABD01	450238106544301	WR-22	3,690	357	Tft	A-Dz1-Dz2	229.40 231.00 227.95 230.48 229.37	09-18-75 01-08-76 07-15-76 04-19-78 03-25-81	BM
09S39E14DABD02	450238106544302	WR-22A	3,690	185	Tft	O(A-Dz1-Dz2)	172.97 169.42 152.77	03-12-77 04-19-78 03-25-81	BM
09S39E16AABA01	450309106570201	WR-19	3,835	305	Tft	Dz1-Dz2	135.40 126.46	10-08-79 03-25-81	BM
09S39E16AABA02	450309106570301	WR-20	3,835	166	Tft	A	111.22 89.76 90.32 90.26 93.72	09-18-75 09-28-77 04-19-78 11-05-79 03-25-81	BM
09S39E20DABB01	450151106582601	WR-35	3,887	310	Tft	Dz1-Dz2	122.74 122.44 123.33 121.17	06-22-77 08-02-77 04-18-78 11-08-79	BM
09S39E23DACC01	450141106544801	WR-18	3,702	381	Tft	A-Dz1-Dz2	235.63 236.02 236.78 235.33 235.08	08-09-75 04-19-76 01-20-77 05-11-77 03-26-81	BM
09S39E23DACC02	450141106544802	WR-18A	3,703	111	Tft	O(A-Dz1-Dz2)	55.33 57.12 70.25	09-26-79 11-05-79 03-25-81	BM
09S39E24ACDB01	450156106533701	---	3,600	235	Tft	A-Dz1-Dz2	88.0	08-26-75	GS, BM
09S39E24DCDC01	450126106534401	---	3,608	244	Tft	A-Dz1-Dz2	106.0	08-26-75	GS, BM
09S39E25DADB01	450050106532501	WR-54	3,630	384	Tft	A-Dz1-Dz2	165.09 165.06 165.42 166.46	09-28-77 10-26-77 04-19-78 03-25-81	BM
09S39E25DDAA01	450045106532001	WR-53	3,607	384	Tft	A-Dz1-Dz2	142.03 142.32 143.65	09-28-77 04-19-78 03-25-81	BM
09S39E28CCAD01	450044106575401	WR-36	3,716	192	Tft	Dz1-Dz2	32.28 31.34 32.66 33.92 32.54	06-22-77 08-30-77 10-25-77 04-18-78 12-06-79	BM
09S39E28CCAD02	450044106575402	WR-37	3,716	126	Tft	A	29.86 29.89 22.90 29.11 29.65 30.27	06-22-77 08-02-77 09-27-77 10-25-77 04-18-78 12-06-79	BM
09S39E28DACD01	450048106571001	WR-47	3,816	367	Tft	A-Dz1-Dz2	222.18 222.70 222.99	08-02-77 04-18-78 12-06-79	BM
09S39E29ABAA01	450121106583401	WR-26	3,770	267	Tft	A	75.26 75.21 75.76 74.38 76.57 76.08	02-04-76 03-05-76 04-07-76 07-14-76 04-18-78 11-08-79	BM
09S39E29CBAA01	450059106591101	WR-30	3,895	428	Tft	Dz1-Dz2	196.98 196.06 197.60 198.59	06-22-77 09-27-77 04-18-78 03-22-81	BM
09S39E29CBAA02	450059106591102	WR-31	3,895	316	Tft	A	180.05 182.28 181.32	06-22-77 04-18-78 03-22-81	BM

Table 1.--Records of selected wells in the West Decker Mine study area--Continued

Well number	Site identification number	Other well designation	Altitude of land surface (feet)	Depth of well below land surface (feet)	Geo-hydro-logic unit	Aquifer zone	Depth to water below land surface (feet)	Date water level measured (month-day-year)	Source of data
09S39E32ACAA01	450024106583301	WR-33	3,732	158	Tft	Dz1-Dz2 and Cl(Dz1-Dz2)	46.42	06-22-77	BM
							45.87	08-30-77	
							47.10	09-27-77	
							47.78	10-25-77	
							48.98	04-18-78	
49.91	03-24-81								
09S39E32BCAC01	450022106591301	WR-32	3,849	171	Tft	Dz1-Dz2	95.93	08-02-77	BM
							95.83	10-25-77	
							96.00	04-18-78	
							95.25	02-05-80	
09S39E33CBBB01	450012106580801	WR-34	3,772	522	Tft	A-Dz1-Dz2	123.29	08-02-77	BM
							128.38	04-18-78	
							144.86	03-24-81	
09S39E33DBBD01	450003106565701	WR-27	3,672	363	Tft	A-Dz1-Dz2	57.61	02-04-76	BM
							56.38	03-05-76	
							57.48	03-25-76	
							56.70	04-07-76	
							59.38	10-25-77	
							59.25	04-18-78	
64.76	03-24-81								
09S39E35BADB01	450025106551501	WR-28	3,655	364	Tft	A-Dz1-Dz2	188.16	03-06-76	BM
							189.01	03-19-77	
							187.93	08-02-77	
							188.19	04-19-78	
							187.89	03-24-81	
09S40E03DABA01	450424106483401	WRN-10	3,433	79	Tft	Dz2	17.39	01-06-75	BM
							16.52	02-08-75	
							12.42	04-04-75	
							14.31	06-04-75	
							20.70	10-11-75	
							8.99	07-06-77	
							16.01	04-17-78	
							28.75	03-26-81	
09S40E03DABA02	450424106483402	WRN-11	3,437	50	Tft	A-Dz1 and Cl(A-Dz1)	18.99	01-06-75	BM
							18.64	06-04-75	
							19.55	02-23-77	
							14.76	07-06-77	
							19.32	04-17-78	
19.45	03-26-81								
09S40E04BCAA01	450437106525401	WRN-12	3,525	77	Tft	A-Dz1 and Cl(A-Dz1)	70.70	01-06-75	BM
							69.98	06-04-75	
							69.23	07-10-75	
							72.01	03-12-76	
							71.13	04-20-78	
70.86	03-26-81								
09S40E04CABC01	450421106502801	WRN-13	3,515	124	Tft	Dz2	65.91	01-07-75	BM
							65.78	03-04-75	
							63.15	06-04-75	
							67.13	10-21-77	
							66.70	04-20-78	
							66.93	03-26-81	
09S40E04CABC02	450421106502802	WRN-14	3,514	78	Tft	A-Dz1	66.60	01-07-75	BM
							65.68	02-08-75	
							66.29	06-04-75	
							65.75	08-08-75	
							62.96	02-05-76	
							65.42	04-20-78	
							65.32	03-26-81	
09S40E07CCAB01	450323106530701	---	3,720	274	Tft	A-Dz1-Dz2 and O(A-Dz1-Dz2)	138.0	10-11-73	GS, BM
09S40E08DCAA01	450319106511201	WR-03	3,612	215	Tft	A-Dz1	159.23	11-25-70	BM
							158.60	04-22-72	
							169.49	09-15-73	
							180.57	06-04-75	
							187.34	08-01-77	
							186.45	11-29-77	
							197.37	03-26-81	

Table 1.--Records of selected wells in the West Decker Mine study area--Continued

Well number	Site identification number	Other well designation	Altitude of land surface (feet)	Depth of well below land surface (feet)	Geo-hydro-logic unit	Aquifer zone	Depth to water below land surface (feet)	Date water level measured (month-day-year)	Source of data								
09S40E09AADD01	450350106493901	WRN-15	3,500	143	Tft	Dz2	72.70	01-07-75	BM								
							73.34	04-04-75									
							73.37	05-01-75									
							73.79	06-04-75									
							78.05	07-16-76									
							76.51	04-20-78									
76.38	03-26-81																
09S40E09AADD02	450350106493902	WRN-16	3,500	84	Tft	C1(A-Dz1)	80.84	01-07-75	BM								
							81.15	06-04-75									
							77.33	07-16-76									
							83.04	03-22-78									
							82.61	04-20-78									
							83.62	03-26-81									
09S40E09BDDA01	450337106501601	WR-02	3,595	192	Tft	A-Dz1	150.16	10-16-70	BM								
							158.96	12-20-72									
09S40E09BDDA02	450337106501602	WR-14	3,598	192	Tft	A-Dz1	157.61	09-26-72	BM								
							163.47	09-15-73									
							179.40	06-04-75									
							182.02	05-12-77									
							181.73	04-20-78									
							184.01	04-15-80									
09S40E09BDDB01	450337106501901	WR-13	3,592	247	Tft	Dz2	152.20	09-26-72	BM								
							150.89	04-22-73									
							154.49	09-15-73									
							156.50	06-04-75									
							168.67	09-26-77									
							167.03	04-20-78									
167.72	11-25-80																
09S40E09DBAD01	450330106500101	WD 2225	3,517	120	Sp	----	103.41	08-07-81	GS								
09S40E09DBAD02	450331106500201	WD 2226	3,517	120	Sp	----	104.55	08-08-81	GS								
09S40E09DCAB01	450320106500201	DS-5A	3,506	166	Tft	Dz2	82.68	06-22-76	BM								
							71.42	12-11-76									
							74.15	04-12-77									
							74.42	05-09-77									
							75.62	07-05-77									
							75.36	08-01-77									
							73.32	01-24-78									
							75.41	04-19-78									
							74.01	08-29-79									
							61.83	07-15-80									
							75.58	03-26-81									
09S40E09DCAB02	450320106500202	DS-5B	3,506	140	Sp	----	89.34	06-22-76	BM								
							88.12	07-15-76									
							84.00	04-15-77									
							85.60	07-22-77									
							83.46	11-29-77									
							85.66	04-04-78									
							86.78	04-19-78									
							81.64	06-11-80									
							82.37	08-13-80									
							84.04	03-26-81									
							09S40E09DCAB03	450320106500203		DS-5C	3,506	93	Sp	----	85.01	06-22-76	BM
87.37	04-12-77																
Dry	06-06-77																
86.05	04-04-78																
92.49	04-19-78																
85.55	08-28-79																
84.02	06-11-80																
83.84	08-13-80																
87.27	03-26-81																
09S40E10DDBA01	450321106483701	--	3,452	160	Tft	Dz2 and I(Dz2--C)			23.0						11-17-71	BM	
09S40E11CBCC01	450324106481801	WRN-17	3,424	104	Tft	Dz2			9.42						01-07-75	BM	
							7.74	06-04-75									
							6.57	04-07-76									
							6.97	05-06-76									
							2.69	06-07-77									
							8.36	04-19-78									
							20.41	03-26-81									

Table 1.--Records of selected wells in the West Decker Mine study area--Continued

Well number	Site identification number	Other well designation	Altitude of land surface (feet)	Depth of well below land surface (feet)	Geo-hydro-logic unit	Aquifer zone	Depth to water below land surface (feet)	Date water level measured (month-day-year)	Source of data								
09S40E15CACD01	450231106491201	DS-3	3,435	63	Sp	----	60.23	06-22-76	BM								
							58.30	07-15-76									
							36.05	04-12-77									
							25.46	07-05-77									
							29.46	07-22-77									
							35.14	04-04-78									
							36.55	04-19-78									
							23.73	02-27-79		GS							
							23.66	08-28-79		BM							
							26.53	03-26-81									
09S40E15CBDA01	450238106492101	DS-4	3,435	67	Sp	----	60.66	06-22-76	BM								
							56.30	07-15-76									
							52.98	04-11-77									
							44.62	07-22-77									
							43.11	03-20-78									
							41.93	04-04-78									
							43.44	04-19-78									
							38.28	02-27-79									
							36.94	08-28-79		GS							
							36.61	06-11-80		BM							
34.62	08-13-80																
33.46	03-26-81																
09S40E15CDBC01	450225106491301	DS-1A	3,458	88	Sp	----	84.65	05-02-75	BM								
							85.79	06-05-75									
							82.18	10-02-75									
							80.08	01-06-76									
							79.40	03-24-76									
							52.99	03-20-78									
							58.99	04-19-78									
							46.65	03-26-81									
							09S40E15CDBC02	450225106491302		DS-1B	3,458	95	Sp	----	83.60	05-02-75	BM
															85.73	06-05-75	
80.84	10-02-75																
80.51	12-03-75																
78.18	04-13-76																
77.89	06-04-76																
72.01	11-20-76																
55.38	07-05-77																
56.76	08-01-77																
46.38	03-26-81																
09S40E15CDBC03	450223106491401	DS-7A	3,458	84	Sp	----	53.31	02-22-78	BM								
							52.66	03-20-78									
							52.69	04-04-78									
							58.73	04-19-78									
							44.00	08-28-79									
							43.14	07-15-80									
							46.06	08-13-80									
							46.35	03-26-81									
							09S40E15CDBC04	450223106491402		DS-7B	3,458	92	Sp	----	53.31	02-22-78	BM
															52.36	03-20-78	
52.40	04-04-78																
57.25	04-19-78																
45.41	02-27-79																
43.60	08-28-79																
43.46	07-15-80																
45.68	08-13-80																
46.23	03-26-81																
09S40E15DBCC01	450230106490001	DS-2A	3,430	150	Tft	Dz2			-3.21						06-21-76	BM	
							-3.23	06-22-76									
							-1.35	06-26-76									
							5.40	08-28-79									
							7.01	06-11-80									
							6.99	07-15-80									
							7.62	03-26-81									
09S40E15DBCC02	450230106490002	DS-2B	3,430	74	Sp	----	22.01	06-22-76	BM								
							21.19	07-15-76									
							2.49	02-18-77									
							18.50	04-12-77									
							19.16	04-04-78									
							20.57	04-19-78									
							17.12	08-28-79									
							17.90	05-14-80									
							18.35	08-13-80									
							18.22	03-26-81									

Table 1.--Records of selected wells in the West Decker Mine study area--Continued

Well number	Site identification number	Other well designation	Altitude of land surface (feet)	Depth of well below land surface (feet)	Geo-hydro-logic unit	Aquifer zone	Depth to water below land surface (feet)	Date water level measured (month-day-year)	Source of data
09S40E15DBCC03	450230106490003	DS-2C	3,430	65	Sp	----	42.42	06-22-76	BM
							41.40	07-15-76	
							15.68	07-05-77	
							35.50	04-04-78	
							36.55	04-19-78	
							17.50	08-28-79	
09S40E16ABCA01	450258106500701	WR-01	3,498	104	Tft	A-Dz1	23.81	03-26-81	GS BM
							56.13	10-16-70	
							50.00	03-03-72	
							81.62	09-15-73	
							93.12	06-04-75	
							95.77	02-06-76	
09S40E16ABCD01	450258106500702	WR-06	3,499	135	Tft	A-Dz1	79.43	04-19-78	BM
							82.73	03-26-81	
							55.97	06-12-71	
							54.70	08-13-71	
							81.49	09-15-73	
							92.57	06-04-75	
09S40E16ABCD02	450258106500703	WR-07	3,498	207	Tft	Dz2	95.47	02-05-76	BM
							94.54	04-06-76	
							94.18	05-03-76	
							86.23	02-22-78	
							78.55	04-19-78	
							66.34	08-28-79	
09S40E16BABD01	450302106502601	DS-6A	3,515	157	Sp	----	83.53	03-26-81	BM
							108.07	06-22-76	
							108.82	07-15-76	
							108.83	07-16-76	
							97.34	04-15-77	
							89.00	04-04-78	
09S40E16BABD02	450302106502602	DS-6B	3,515	130	Sp	----	89.50	04-19-78	BM
							85.98	08-28-79	
							84.66	06-11-80	
							84.80	08-13-80	
							104.40	07-15-76	
							104.40	07-16-76	
09S40E17ACAC01	450252106511700	--	3,545	115	Tft	A-Dz1	101.71	04-15-77	BM GS
							97.54	04-04-78	
							98.72	04-19-78	
							99.96	11-25-80	
							---	08-14-70	
							110.9	10-12-73	
09S40E17DACB01	450231106510501	WR-04	3,585	220	Tft	A-Dz1	131.36	04-22-72	BM
							147.53	09-15-73	
							156.87	06-04-75	
							163.12	09-16-76	
							159.61	11-29-77	
							174.86	03-26-81	
09S40E17DACC01	450231106510502	WR-12	3,586	230	Tft	A-Dz1	176.55	03-26-81	BM
							138.98	09-26-72	
							149.50	09-15-73	
							158.77	06-04-75	
							164.93	06-09-77	
							161.81	04-20-78	
09S40E18ABAD01	450302106522601	WR-16	3,640	237	Tft	A-Dz1-Dz2	184.0	06-04-74	BM
							188.20	06-04-75	
							194.55	04-12-77	
							193.11	09-26-77	

Table 1.--Records of selected wells in the West Decker Mine study area--Continued

Well number	Site identification number	Other well designation	Altitude of land surface (feet)	Depth of well below land surface (feet)	Geo-hydro-logic unit	Aquifer zone	Depth to water below land surface (feet)	Date water level measured (month-day-year)	Source of data
09S40E19BACA01	450205106525401	WR-15	3,685	390	Tft	A-Dz1-Dz2	236.38 239.01 242.88 240.78 244.18	06-03-74 06-04-75 02-22-77 04-19-78 03-25-81	BM
09S40E19CBBD01	450148106530901	WR-55	3,591	288	Tft	A-Dz1-Dz2	127.10 127.43 129.25 128.60 129.12	09-28-77 04-19-78 09-26-79 02-06-80 03-25-81	BM
09S40E19CBBD02	450149106531101	WR-55A	3,591	72	Tft	O(A-Dz1-Dz2)	45.04 46.12 45.06	09-26-79 11-07-79 03-25-81	BM
09S40E20BDAC01	450159106513701	WR-60	3,665	380	Tft	A-Dz1	241.29	08-05-81	GS
09S40E20BDAC02	450159106513601	WR-61	3,665	380	Tft	A-Dz1	241.21	08-06-81	GS
09S40E21ACCA01	450152106500701	WR-08	3,533	165	Tft	A-Dz1	90.41 103.51 111.29 115.53 115.36 115.72 110.70 120.11	09-30-72 09-15-73 06-04-75 11-16-76 12-11-76 01-22-77 04-20-78 03-26-81	BM
09S40E21ACCA02	450152106500702	WR-09	3,533	255	Tft	Dz2	67.64 73.22 80.48 94.06 101.85	09-30-72 09-15-73 06-04-74 04-20-78 03-26-81	BM
09S40E21BCAC01	450157106503700	WR-11	3,575	210	Tft	A-Dz1	128.25 139.01 146.94 151.67 148.79 156.96	09-26-72 09-15-73 06-04-75 01-22-77 08-29-77 03-26-81	BM
09S40E21BCAD01	450157106503500	WR-05	3,574	200	Tft	A-Dz1	105.84 109.15	11-24-70 09-15-73	BM
09S40E21CACD01	450140106502600	--	3,556	110	Tft	O(A-Dz1)	---	10-14-72	BM
09S40E21CADA01	450139106501601	WR-10	3,537	196	Tft	A-Dz1	92.46 103.78 111.95 116.11 111.35 120.22	09-25-72 09-15-73 06-04-75 01-22-77 04-20-78 03-25-81	BM
09S40E21CDBD01	450135106502600	--	3,561	188	Tft	A-Dz1	142.7	10-12-73	GS
09S40E29BBAC01	450118106515101	WR-17	3,574	300	Tft	A-Dz1-Dz2	111.65 112.86 111.48 114.98 117.81 113.32 118.11	06-03-74 06-04-74 11-04-74 06-04-75 12-11-76 04-20-78 03-25-81	BM
09S40E29BDCB01	450107106514401	WR-51	3,541	344	Tft	A-Dz1-Dz2	76.18 77.23 81.79 81.56 81.99	07-06-77 04-20-78 09-26-79 11-07-79 03-25-81	BM
09S40E29BDCB02	450107106514402	WR-51A	3,541	187	Tft	O(A-Dz1-Dz2)	56.82 56.15 59.32	09-26-79 11-07-79 03-25-81	BM
09S40E29CCAD01	450044106514601	--	3,523	153	Tft	A-Dz1	39.00	08-14-70	GS, BI
09S40E29CCAD02	450044106514802	--	3,520	151	Tft	A-Dz1	39.00 39.00	02-27-72 10-16-73	BM GS

Table 2.--Common-constituent concentrations in water from selected wells in the West Decker Mine study area

[Constituents are dissolved and concentrations are reported in milligrams per liter. Analyses by Montana Bureau of Mines and Geology. Aquifer zone: Cl, clinker; A, Anderson coal bed; Dz2, Dietz 2 coal bed; C, Canyon coal bed; A-Dz1, combined Anderson-Dietz 1 coal bed; A-Dz1-Dz2, combined Anderson-Dietz 1-Dietz 2 coal bed; Dz1-Dz2, combined Dietz 1-Dietz 2 coal bed; Dz2-C, combined Dietz 2-Canyon coal bed; O, overburden superjacent to unit in parentheses; I, interburden between units in parentheses; Sp, West Decker Mine spoils. Source of data: BM, Montana Bureau of Mines and Geology; GS, U.S. Geological Survey. Abbreviations: °C, degrees Celsius; micromhos, micromhos per centimeter at 25° Celsius; <, less than]

Well number	Date (month-day-year)	Aquifer zone	Specific conductance (micromhos)	Laboratory pH, units	Temperature (°C)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)
08S40E33ACDB01	10-11-73	Dz2	1,610	7.74	10.5	130	72	180
08S40E34BDAA01	10-11-73	Cl(A-Dz1)	927	7.76	12.0	40	65	75
09S39E01BCBA01	08-04-81	A-Dz1-Dz2	1,800	8.01	17.0	4.3	1.6	450
09S39E14BDAD01	10-17-73	A-Dz1-Dz2	1,370	8.82	14.0	2.6	.8	350
09S39E16AABA01	10-08-79	Dz1-Dz2	1,540	8.33	15.0	2.6	1.4	420
09S39E16AABA02	10-09-79	A	2,440	8.12	14.5	9.9	7.8	660
09S39E23DACC02	10-02-79	O(A-Dz1-Dz2)	6,980	7.91	14.0	91	86	1,940
09S39E28CCAD01	11-04-77	Dz1-Dz2	2,410	7.94	15.5	10	4	590
09S39E28CCAD02	11-04-77	A	1,720	8.16	12.5	4	3	420
09S39E29ABAA01	03-10-76	A	3,990	8.27	15.0	8	6	1,030
09S39E32ACAA01	10-18-77	Dz1-Dz2 and Cl(Dz1-Dz2)	2,390	7.67	11.5	170	240	87
09S39E33DBBD01	03-25-76	A-Dz1-Dz2	1,740	7.97	16.0	4.0	1.4	420
09S40E03DABA01	04-02-75	Dz2	2,380	7.88	12.0	74	57	450
09S40E09AADD01	04-03-75	Dz2	1,600	8.02	11.0	5.2	2.3	420
09S40E09DBAD01	08-07-81	Sp	3,440	8.06	14.0	20	9.1	940
09S40E09DBAD02	08-08-81	Sp	3,450	8.1	14.0	22	9.5	980
09S40E09DCAB01	04-14-77	Dz2	1,730	8.66	15.5	4.7	1.7	430
	07-22-77		1,090	7.7	14.0	31	23	190
	04-04-78		1,270	7.28	14.0	35	27	230
	08-28-79		1,290	7.74	11.0	39	23	240
	07-15-80		1,550	7.96	14.0	29	21	320
09S40E09DCAB02	07-15-76	Sp	1,930	8.26	14.0	6.0	3.5	500
	04-15-77		1,740	8.37	13.5	5.9	3.0	450
	07-22-77		1,650	8.11	14.0	6.8	4.0	410
	04-04-78		1,790	7.66	13.0	8.2	3.9	470
	02-27-79		289	6.79	--	23	6.3	27
	07-15-80		4,160	8.96	13.5	10	15	1,170
09S40E09DCAB03	04-12-77	Sp	3,490	7.94	13.5	38	35	800
	04-04-78		1,770	6.96	13.0	93	36	290
	08-28-79		6,560	8.12	11.0	9	49	1,750
	07-15-80		5,370	8.13	14.0	54	5	1,300
09S40E10DDBA01	11-17-71	Dz2 and I(Dz2-C)	1,710	8.09	10.5	5.7	.4	440
09S40E11CBCC01	04-15-76	Dz2	1,640	8.1	12.5	6.1	1.8	430
09S40E15CACD01	07-15-76	Sp	6,800	7.52	15.8	170	130	1,450
	04-12-77		7,150	7.81	10.0	380	260	1,180
	07-22-77		8,120	6.93	10.0	520	330	1,450
	04-04-78		8,280	6.82	11.0	500	340	1,460
	02-27-79		7,930	7.30	11.0	470	330	1,450
	08-28-79		7,020	7.85	11.0	290	260	1,300
09S40E15CBDA01	07-15-76	Sp	2,040	7.98	7.0	13	18	500
	04-11-77		2,130	8.80	7.5	11	15	520
	07-22-77		2,570	7.73	8.5	18	14	610
	04-04-78		2,440	7.70	8.5	14	11	580
	02-27-79		2,150	7.90	9.0	11	9.2	560
	08-28-79		2,260	8.21	11.0	11	11	580
	07-14-80		---	8.37	9.5	17	22	640

Potas- sium (K)	Bicar- bonate (HCO ₃)	Carbo- nate (CO ₃)	Sul- fate (SO ₄)	Chlo- ride (Cl)	Fluo- ride (F)	Silica (SiO ₂)	Dissolved solids, calculated	Nitrate as (N)	Source of data
12	350	0	700	5.7	0.3	13	1,290	1.4	GS
9	200	0	350	4.4	.5	28	773	1.2	GS
4	1,180	0	23	10	2.1	9.4	1,090	.1	GS
4	870	28	10	3.5	2.8	8.8	1,290	.98	GS
8	1,120	8	8.2	3.6	2.8	9.7	1,020	1.4	BM
7	870	0	720	13	2.4	8.7	1,860	.32	BM
17	1,560	0	3,400	25	.6	7.6	6,290	6.2	BM
5	940	0	500	15	1.8	12	1,600	<.02	BM
5	710	0	340	6	2.1	52	1,190	.23	BM
8	1,760	0	830	10	2.9	10	2,770	0.02	BM
20	480	0	1,100	11	.7	36	1,910	8.3	BM
10	870	0	190	9.9	1.2	11	1,070	.36	BM
13	700	0	790	13	2.0	15	1,750	.07	BM
4	1,130	0	2.8	7.1	2.2	20	1,020	.11	BM
8	1,780	0	680	8.7	1.8	11	2,550	1.6	GS
9	1,810	0	690	7.3	1.7	10	2,630	.15	GS
5	1,190	26	1.7	7.0	3.8	8.8	1,070	.05	BM
7	430	0	200	22	.6	9.0	702	.63	
8	510	0	250	2.8	.7	10	810	1.7	
9	520	0	270	2.3	.8	9.4	844	.63	
8	710	0	250	3.5	1.7	10	993	.02	
7	1,330	0	30	7.8	4.6	14	1,230	.04	BM
5	1,110	5	1.6	61	4.8	14	1,090	<.02	
6	1,060	0	56	7.0	3.7	16	1,040	.03	
5	1,260	0	20	6.0	4.2	11	1,150	.03	
10	180	0	9.2	1.2	.2	5.4	169	.31	
14	2,450	84	510	11	.2	9.3	3,030	<.02	
16	1,600	0	710	14	.6	8.2	2,430	21	BM
12	950	0	230	5.0	.5	10	1,140	.04	
20	2,750	0	1,700	20	.8	7.7	4,920	4.5	
1	2,970	0	510	27	.7	21	3,380	<.02	
7	1,190	0	4.8	7.1	3.6	4.0	1,670	.02	BM
4	1,140	0	6.7	25	4.4	8.3	1,050	.05	BM
32	1,210	0	3,000	31	1.0	11	5,380	.34	BM
58	1,220	0	3,400	61	.6	30	5,950	24	
52	1,430	0	4,400	65	.4	29	7,540	.81	
54	1,490	0	4,500	41	.5	32	7,620	.06	
42	1,340	0	4,000	45	.5	33	7,050	5.3	
50	1,310	0	3,500	20	1.0	32	6,100	1.8	
8	1,370	0	56	18	1.6	10	1,290	1.2	BM
8	1,330	64	100	12	.5	12	1,400	.33	
7	1,200	0	450	10	1.7	16	1,720	.08	
6	1,180	0	390	8.0	2.1	14	1,610	.04	
6	1,320	0	160	21	2.3	15	1,440	.19	
7	1,260	0	240	25	2.3	13	1,510	1.9	
8	1,370	20	320	29	1.8	13	1,740	.07	

Table 2.--Common-constituent concentrations in water from selected wells in the West Decker Mine study area--Continued

Well number	Date (month-day-year)	Aquifer zone	Specific conductance (micro-mhos)	Laboratory pH, units	Temperature (°C)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)
09S40E15CDBC01	05-02-75	Sp	4,390	7.19	10.0	67	66	1,000
	10-02-75		4,610	7.98	--	66	80	1,070
	01-06-76		4,660	7.59	8.0	66	70	1,140
	03-24-76		4,570	7.46	15.5	72	56	1,090
09S40E15CDBC02	05-02-75	Sp	7,280	6.84	13.0	200	63	1,640
	10-02-75		4,300	9.23	--	49	35	1,080
	12-03-75		4,220	7.29	12.5	51	39	990
	04-13-76		6,090	7.05	14.5	76	34	1,440
	06-04-76		4,240	7.39	13.5	53	42	990
	11-20-76		3,970	7.75	12.0	43	34	960
09S40E15CDBC03	04-04-78	Sp	2,990	7.18	10.5	33	21	700
	08-28-79		2,650	7.99	11.0	30	19	630
	07-16-80		3,190	7.82	12.0	40	31	720
09S40E15CDBC04	04-04-78	Sp	3,910	7.06	10.5	54	44	910
	02-27-79		3,280	8.00	10.0	37	28	810
	08-28-79		3,100	8.22	11.0	14	26	760
	07-17-80		3,930	7.54	12.5	45	27	950
09S40E15DBCC01	06-04-76	Dz2	2,200	7.93	13.0	5.9	2.5	530
	08-28-79		202	6.91	13.0	12	6.5	17
	07-14-80		---	7.31	10.0	14	6	20
09S40E15DBCC02	07-15-76	Sp	2,200	8.25	12.0	12	8.2	560
	04-12-77		1,840	8.51	12.5	14	8.5	450
	04-04-78		1,970	8.12	12.5	25	22	440
	08-28-79		2,150	8.26	11.0	13	10	560
	07-14-80		1,600	8.25	10.5	20	15	360
09S40E15DBCC03	07-15-76	Sp	2,460	8.04	16.0	21	21	580
	04-04-78		3,250	7.50	--	100	90	600
	08-28-79		137	7.00	11.0	8.9	4.0	9.4
09S40E16ABCD01	08-14-71	A-Dz1	1,590	8.2	12.0	4.2	.7	440
	04-07-76		1,630	8.12	13.0	4	2	430
	04-04-78		1,610	7.70	12.0	4	2	420
	08-28-79		1,690	7.78	11.0	4	2	450
09S40E16ABCD02	08-13-71	Dz2	1,520	8.2	14.0	4.6	1.0	410
09S40E16BABD01	07-15-76	Sp	1,680	8.10	14.0	4.4	1.8	440
	04-15-77		1,730	8.68	--	5.8	2.2	440
	04-04-78		1,670	8.07	13.0	4.5	1.8	440
	08-28-79		1,700	8.09	11.0	5	2	460
	07-15-80		665	6.47	14.0	21	8	120
09S40E16BABD02	07-15-76	Sp	2,070	7.65	14.0	13	7	540
	04-15-77		2,200	7.70	--	16	9	560
	04-04-78		2,510	7.74	13.5	22	11	630
09S40E17ACAC01	08-14-70	A-Dz1	1,550	7.9	13.0	1	1.4	430
	07-14-72		1,870	8.69	12.0	3.8	1.6	500
09S40E18ABAD01	05-14-74	A-Dz1-Dz2	1,640	7.92	--	5.2	1.9	420
09S40E19CBBD01	10-06-79	A-Dz1-Dz2	1,260	8.33	14.5	2	1	360
09S40E19CBBD02	10-07-79	O(A-Dz1-Dz2)	7,360	8.06	12.0	24	28	2,210
09S40E20BDAC01	08-05-81	A-Dz1	2,630	7.93	15.0	11	4.3	690
09S40E20BDAC02	08-06-81	A-Dz1	2,190	8.03	15.0	14	5.3	710
09S40E21ACCA01	11-20-76	A-Dz1	2,690	8.27	10.5	8.6	2.8	730
09S40E21CACD01	10-14-72	O(A-Dz1)	5,010	8.40	15.0	31	13	1,400
	08-30-79		1,450	8.11	14.0	3.2	.9	440
09S40E21CDBD01	10-12-73	A-Dz1	1,690	8.54	11.0	2	1	440
	08-30-79		1,690	8.54	11.0	2	1	440
09S40E29BBAC01	06-04-74	A-Dz1-Dz2	1,820	8.91	--	5.9	2.5	460
09S40E29BDCB01	10-03-79	A-Dz1-Dz2	2,120	8.16	13.0	5	3	590
09S40E29BDCB02	10-02-79	O(A-Dz1-Dz2)	2,430	8.02	13.0	13	18	680
09S40E29CCAD01	08-14-70	A-Dz1	1,690	8.4	10.0	4.6	.5	430
09S40E29CCAD02	07-27-72	A-Dz1	1,740	9.50	11.0	3.2	1.6	460

Potas- sium (K)	Bicar- bonate (HCO ₃)	Carbo- nate (CO ₃)	Sul- fate (SO ₄)	Chlo- ride (Cl)	Fluo- ride (F)	Silica (SiO ₂)	Dissolved solids, calculated	Nitrate as (N)	Source of data
16	1,550	0	1,200	30	.6	13	3,200	.23	BM
19	1,930	0	1,200	21	.6	12	3,390	5.0	
18	2,270	0	950	22	.6	11	3,390	2.9	
17	2,060	0	1,000	19	.6	9.4	3,300	.32	
16	880	0	3,500	21	.3	20	5,860	.45	BM
17	1,580	180	900	16	.8	7.7	3,060	4.1	
16	1,920	0	830	16	.7	8.3	2,890	.52	
14	1,080	0	2,400	--	.3	18	4,530	.05	
16	1,960	0	860	15	.6	8.3	2,940	.03	
15	1,940	0	710	39	.7	7.9	2,760	.07	
11	1,340	0	570	11	.7	10	2,020	.03	BM
10	1,110	0	560	14	.6	8.1	1,810	2.7	
12	1,460	0	570	11	.2	8.9	2,110	3.7	
13	1,760	0	830	8.0	.5	14	2,730	.02	BM
12	1,610	0	610	17	.7	20	2,320	<.02	
12	1,600	0	460	12	.5	9.3	2,080	3.1	
11	1,570	0	940	10	.2	15	2,770	2.2	
5	1,460	0	4.5	24	1.3	8.2	1,300	<.02	BM
6	88	0	21	2.2	.1	3.2	113	.32	
6	95	0	25	2.9	.1	3.8	124	.23	
10	1,380	0	110	9.0	3.3	15	1,410	.46	BM
8	1,150	19	82	16	2.9	20	1,180	.15	
10	990	0	260	13	2.4	11	1,270	<.02	
8	1,340	0	130	19	3.6	13	1,420	1.6	
8	1,030	0	47	19	1.8	11	989	<.02	
9	1,250	0	350	21	2.8	12	1,630	.03	BM
11	820	0	1,100	32	1.6	17	2,380	.25	
6	63	0	13	1.7	.1	3.5	78	.38	
6	1,160	0	6.6	5.0	3.5	3.5	1,620	.00	BM
4	1,140	0	1	24	3.9	9.1	1,030	.33	
4	1,140	0	0	7.0	3.7	10	1,010	<.02	
4	1,100	0	52	6.9	4.0	9.4	1,080	2.3	
6	1,090	0	3.8	5.1	4.3	3.5	1,530	.00	BM
5	1,180	0	1.7	6.2	3.7	11	1,060	1.4	BM
5	1,070	33	1.6	22	3.8	11	1,050	<.02	
4	1,200	0	2.5	5.0	3.9	9.2	1,060	.03	
5	1,190	0	1	6.1	4.1	9.0	1,080	2.4	
12	400	0	10	5.3	1.0	12	388	<.02	
7	1,370	0	84	6.5	3.6	8.0	1,340	.44	BM
7	1,510	0	28	5.0	3.4	9.1	1,380	2.0	
8	1,550	0	200	10	3.2	7.7	1,650	<.02	
--	1,150	0	1.0	5.1	1.0	8.3	1,620	---	BM
4	950	18	270	5.1	2.9	19	1,870	1.4	
4	1,120	0	5.5	7.5	3.3	11	1,010	1.1	BM
3	920	3	1	5.3	4.5	8.9	838	.03	BM
14	3,190	0	2,200	20	.5	11	6,110	<.02	BM
6	1,500	0	250	19	2.8	9.1	1,730	.03	GS
8	1,480	0	370	22	2.0	9.0	1,870	.06	GS
6	1,840	0	4.8	71	1.6	10	1,740	2.4	BM
--	2,000	19	1,300	16	.4	8.6	4,800	7.2	BM
4	1,140	0	4.7	15	1.3	8.6	1,620	.00	GS
4	1,080	26	0	20	3.2	8.6	1,040	.02	BM
4	1,110	58	3.7	25	3.3	9.2	1,110	<.02	BM
5	1,510	0	59	24	2.1	7.8	1,440	<.02	BM
7	1,560	0	270	16	1.6	11	1,780	.27	BM
--	1,190	7	4	.3	1.2	7.1	1,650	.5	BM
4	990	100	22	14	2.2	17	1,600	<.02	BM

Table 3.--Trace-element concentrations in water from selected wells in the West Decker Mine study area

[Constituents are dissolved and concentrations are reported in micrograms per liter except as indicated. Analyses by Montana Bureau of Mines and Geology. Aquifer zone: A, Anderson coal bed; Dz2, Dietz 2 coal bed; A-Dz1, combined Anderson-Dietz 1 coal bed; A-Dz1-Dz2, combined Anderson-Dietz 1-Dietz 2 coal bed; Dz1-Dz2, combined Dietz 1-Dietz 2 coal bed; Sp, West Decker Mine spoils; O, overburden superjacent to unit in parentheses. Source of data: BM, Montana Bureau of Mines and Geology; GS, U.S. Geological Survey. Symbol: <, less than]

Well number	Date of sample (month-day-year)	Aquifer zone	Aluminum (Al)	Antimony (Sb)	Arsenic (As)	Beryllium (Be)	Boron (B)	Cadmium (Cd)	Chromium (Cr)	Copper (Cu)
09S39E01BCBA01	08-04-81	A-Dz1-Dz2	<30	--	--	--	130	<2	<2	<2
09S39E16AABA01	10-08-79	Dz1-Dz2	--	--	--	--	--	--	--	--
09S39E16AABA02	10-09-79	A	--	--	--	--	--	--	--	--
09S40E09DBAD01	08-07-81	Sp	<30	--	--	--	<20	<2	<2	<2
09S40E09DBAD02	08-08-81	Sp	80	--	--	--	160	<2	8	16
09S40E09DCAB01	08-28-79 07-15-80	Dz2	-- 50	-- <200	-- <1	-- --	70 140	-- <10	-- <10	-- <10
09S40E09DCAB02	07-15-76 04-15-77 07-22-77 04-04-78 02-27-79 07-15-80	Sp	-- 600 300 -- -- 200	-- <200 <200 -- -- 200	-- <2 <2 -- -- 5	-- <10 <10 -- -- -- --	-- -- -- -- <10 90	-- <10 10 -- -- <10	-- <10 <10 -- -- <10	-- <10 10 -- -- -- <10
09S40E09DCAB03	04-12-77 04-04-78 08-28-79 07-15-80	Sp	50 -- -- 40	<200 -- -- 200	<2 -- -- 2	<10 -- -- --	-- -- 20 60	<10 -- -- <10	20 -- -- <10	10 -- -- <10
09S40E15CACD01	07-15-76 04-12-77 07-22-77 04-04-78 02-27-79 08-28-79	Sp	<50 <50 <50 -- -- --	300 400 700 -- -- --	-- 38 16 -- -- --	-- <10 <10 -- -- -- --	20 -- -- -- -- 290	<10 20 20 -- -- --	<10 30 30 -- -- --	<10 30 40 -- -- --
09S40E15CBDA01	07-15-76 04-11-77 07-22-77 04-04-78 02-27-79 08-28-79 07-14-80	Sp	500 80 200 -- -- -- 60	<200 <200 200 -- -- -- <200	-- <2 2 -- -- -- 3	<10 <10 <10 -- -- -- --	<100 -- -- -- -- 40 70	<10 <10 <10 -- -- -- <10	<10 <10 <10 -- -- -- <10	10 <10 10 -- -- -- <10
09S40E15CDBC01	05-02-75 10-02-75 01-06-76 03-24-76	Sp	-- 100 -- <50	-- <200 -- <200	-- <2 -- <2	-- <10 -- <10	<50 130 -- 130	-- <10 -- <10	-- <10 -- <10	-- 10 -- <10
09S40E15CDBC02	05-02-75 10-02-75 12-03-75 04-13-76 06-04-76 11-20-76	Sp	-- 300 300 100 <50 50	-- <200 200 3,600 <200 <200	-- <2 <2 17 -- <2	-- <10 -- <10 <10 <10	620 160 -- 310 100 170	-- <10 <10 <10 10 10	-- <10 <10 10 <10 <10	-- 10 10 <10 30 20
09S40E15CDBC03	04-04-78 08-28-79 07-16-80	Sp	-- -- <30	-- -- 200	-- -- 6	-- -- --	-- 30 60	-- -- <10	-- -- <10	-- -- <10
09S40E15CDBC04	04-04-78 02-27-79 08-28-79 07-17-80	Sp	-- -- -- 30	-- -- -- <200	-- -- -- 15	-- -- -- --	-- -- 40 140	-- -- -- <10	-- -- -- <10	-- -- -- <10
09S40E15DBCC01	08-28-79 07-14-80	Dz2	-- 50	-- <200	-- <1	-- --	<20 <20	-- <10	-- <10	-- <10
09S40E15DBCC02	07-15-76 04-12-77 04-04-78 08-28-79 07-14-80	Sp	-- 400 -- -- 80	-- <200 -- -- <200	-- <2 -- -- 1	-- <10 -- -- --	-- -- -- 20 <20	-- <10 -- -- <10	-- <10 -- -- <10	-- <10 -- -- <10

Iron (Fe)	Lead (Pb)	Lithium (Li)	Manganese (Mn)	Mercury (Hg)	Nickel (Ni)	Selenium (Se)	Silver (Ag)	Strontium (Sr)	Tin (Sn)	Zinc (Zn)	Source of data
140	<40	120	9	--	10	--	<2	200	--	20	GS
0	--	130	<10	--	--	--	--	--	--	--	BM
0	--	450	290	--	--	--	--	--	--	--	BM
120	<40	230	35	--	<10	--	<2	1,100	--	20	GS
70	<40	240	56	--	20	--	11	1,100	--	30	GS
<10	<40	50	30	--	--	--	--	--	--	--	BM
180	<40	70	40	<.1	<10	<1	<10	0	<10	40	
440	<50	--	10	--	--	--	--	--	--	--	BM
430	<10	140	50	--	10	<2	<10	400	90	20	
320	<10	130	40	--	20	<2	<10	500	60	40	
210	a<50	130	80	--	--	--	--	--	--	--	
90	<50	10	20	--	--	--	--	--	--	--	
170	<40	320	20	<.1	<10	<1	<10	1,400	<10	30	
140	<10	240	710	--	50	<2	<10	2,900	190	50	BM
1,900	a<50	a70	1,400	--	--	--	--	--	--	--	
10	<40	500	<10	--	--	--	--	--	--	--	
10	<10	380	<10	<.1	<10	<1	<10	3,200	<10	20	
20	80	540	390	--	70	--	10	9,000	250	30	BM
50	200	310	390	--	80	<2	10	14,000	840	90	
50	<10	390	1,100	--	90	<2	10	15,000	860	130	
40	a90	a410	1,500	--	--	--	--	--	--	--	
60	a320	a420	2,000	--	--	--	--	--	--	--	
<10	<40	270	10	--	--	--	--	--	--	--	
210	<50	80	90	--	10	--	<10	700	150	10	BM
10	<10	70	<10	--	10	<2	<10	400	120	10	
240	<10	180	200	--	30	<2	<10	1,000	80	60	
30	a<50	a160	540	--	--	--	--	--	--	--	
50	a50	a160	60	--	--	--	--	--	--	--	
<10	<40	150	<10	--	--	--	--	--	--	--	
20	<10	170	280	<.1	<10	<1	<10	1,000	<10	<10	
50	60	--	320	--	--	--	--	--	--	--	BM
260	<50	350	1,300	<.3	60	2	<10	3,200	150	50	
30	a80	--	590	--	--	--	--	--	--	--	
220	<50	380	10	<.3	60	<2	<10	4,400	130	<10	
230	100	--	740	--	--	--	--	--	--	--	BM
410	<50	350	160	<.3	50	2	<10	2,400	90	60	
90	<50	360	190	<.3	60	<2	<10	3,800	--	80	
900	80	400	170	--	70	<2	<10	300	180	90	
10	<50	350	180	<.3	60	2	<10	3,700	130	40	
30	<50	340	160	<.3	50	<2	<10	3,100	480	160	
<10	a<50	a220	130	--	--	--	--	--	--	--	BM
0	<40	160	10	--	--	--	--	--	--	--	
<10	<40	210	150	.3	<10	<1	<10	2,500	--	30	
20	a<50	a290	240	--	--	--	--	--	--	--	BM
10	a<30	a260	10	--	--	--	--	--	--	--	
30	<40	200	10	--	--	--	--	--	--	--	
40	<40	230	70	<.1	<10	<1	20	2,000	--	40	
70	<40	20	20	--	--	--	--	--	--	--	BM
120	<40	90	20	<.1	<10	<1	<10	300	<10	420	
290	<50	--	20	--	--	--	--	--	--	--	BM
400	<10	110	80	--	20	<2	<10	600	150	30	
70	a<50	a110	90	--	--	--	--	--	--	--	
130	<40	130	<10	--	--	--	--	--	--	--	
120	<40	100	40	<.1	<10	<1	<10	700	<10	180	

Table 3.--Trace-element concentrations in water from selected wells in the West Decker Mine study area--Continued

Well number	Date of sample (month-day-year)	Aquifer zone	Aluminum (Al)	Antimony (Sb)	Arsenic (As)	Beryllium (Be)	Boron (B)	Cadmium (Cd)	Chromium (Cr)	Copper (Cu)
09S40E15DBCC03	07-15-76	Sp	400	<200	--	<10	100	<10	<10	20
	04-04-78		--	--	--	--	--	--	--	--
	08-28-79		--	--	--	--	<20	--	--	--
09S40E16ABCD01	08-28-79	A-Dz1	--	--	--	30	--	--	--	
09S40E16BABD01	07-15-76	Sp	800	<200	--	<10	100	<10	<10	10
	04-15-77		500	<200	<2	<10	--	<10	<10	10
	04-04-78		--	--	--	--	--	--	--	--
	08-28-79		--	--	--	--	20	--	--	--
	07-15-80		60	<200	<1	--	60	<10	<10	<10
09S40E16BABD02	07-15-76	Sp	800	<200	--	<10	100	<10	<10	30
	04-15-77		--	--	--	--	--	--	--	--
	04-04-78		--	--	--	--	--	--	--	--
09S40E19CBBD01	10-06-79	A-Dz1-Dz2	--	--	--	--	--	--	--	
09S40E19CBBD02	10-07-79	O(A-Dz1-Dz2)	--	--	--	--	--	--	--	
09S40E20BDAC01	08-05-81	A-Dz1	<30	--	--	--	30	<2	<2	<2
09S40E20BDAC02	08-06-81	A-Dz1	<30	--	--	--	30	2	<2	<2
09S40E21CDBD01	08-30-79	A-Dz1	--	--	--	--	30	--	--	--
09S40E29BDCB01	10-03-79	A-Dz1-Dz2	--	--	--	--	--	--	--	--
09S40E29BDCB02	10-02-79	O(A-Dz1-Dz2)	--	--	--	--	--	--	--	--

^aConcentration is total recoverable.

Iron (Fe)	Lead (Pb)	Lith- ium (Li)	Manga- nese (Mn)	Mer- cury (Hg)	Nickel (Ni)	Sele- nium (Se)	Silver (Ag)	Stron- tium (Sr)	Tin (Sn)	Zinc (Zn)	Source of data
200	<50	140	60	--	<10	--	<10	1,100	80	<10	BM
20	a<50	120	1,300	--	--	--	--	--	--	--	
110	<40	10	20	--	--	--	--	--	--	--	
<10	<40	130	<10	--	--	--	--	--	--	--	BM
540	<50	120	20	--	20	--	<10	300	50	30	BM
290	20	140	30	--	20	<2	<10	300	90	200	
40	a<50	130	10	--	--	--	--	--	--	--	
<10	<40	130	<10	--	--	--	--	--	--	--	
2,000	520	30	80	<.1	<10	<1	<10	300	<10	10	
270	<50	150	140	--	10	--	<10	800	<50	10	BM
120	--	170	110	--	--	--	--	--	--	--	
40	a<50	a190	150	--	--	--	--	--	--	--	
<10	--	110	<10	--	--	--	--	--	--	--	BM
60	--	510	<10	--	--	--	--	--	--	--	BM
110	<40	150	9	--	<10	--	<2	620	--	<10	GS
100	<40	160	9	--	<10	--	<2	720	--	30	GS
<10	<40	120	<10	--	--	--	--	--	--	--	BM
<10	--	150	<10	--	--	--	--	--	--	--	BM
40	--	180	40	--	--	--	--	--	--	--	BM

Table 4.--Representative saturation indices from WATEQF for water from coal aquifers in the West Decker Mine study area

Mineral	Saturation index for indicated well number and date of collection				
	09S39E01BCBA01 (8-04-81)	09S40E09DCAB01 (7-15-80)	09S39E33DBBD01 (3-25-76)	09S40E16ABCD01 (8-28-79)	09S40E20BDAC01 (8-05-81)
Quartz (SiO ₂)	0.32	0.40	0.41	0.43	0.35
Calcite (CaCO ₃)	-.01	.48	-.25	-.37	.30
Aragonite (CaCO ₃)	-.28	.19	-.52	-.67	.01
Dolomite [CaMg(CO ₃) ₂]	-.24	1.00	-.89	-.93	.37
Magnesite (MgCO ₃)	-.54	.22	-.95	-.86	-.23
Albite (NaAlSi ₃ O ₈)	---	-.33	---	---	---
Gypsum (CaSO ₄ ·2H ₂ O)	-3.38	-1.55	-2.51	-3.03	-2.08
Anhydrite (CaSO ₄)	-3.67	-1.88	-2.82	-3.39	-2.39

Table 5.--Representative saturation indices from WATEQF for water
from the West Decker Mine spoils

Mineral	Saturation index for indicated well number and date of collection				
	09S40E09DBAD02 (8-08-81)	09S40E09DCAB02 (7-15-80)	09S40E15CBDA01 (7-14-80)	09S40E15DBCC02 (7-14-80)	09S40E16BABD01 (8-28-79)
Quartz (SiO ₂)	0.40	0.36	0.59	0.50	0.41
Calcite (CaCO ₃)	.72	1.20	.78	.75	.07
Aragonite (CaCO ₃)	.43	.91	.47	.44	-.24
Dolomite [CaMg(CO ₃) ₂]	1.26	2.77	1.78	1.48	-.16
Magnesite (MgCO ₃)	.24	1.27	.71	.44	-.52
Albite (NaAlSi ₃ O ₈)	.32	.66	.69	.30	---
Gypsum (CaSO ₄ ·2H ₂ O)	-1.49	-2.09	-1.80	-2.39	-4.65
Anhydrite (CaSO ₄)	-1.81	-2.42	-2.17	-2.76	-5.01

Table 6.--Common-constituent concentrations in water from batch-mixing experiments using materials from the West Decker Mine area

[Constituents are dissolved and concentrations are reported in milligrams per liter. Analyses by Montana Bureau of Mines and Geology. Source of water: A-Dz1, combined Anderson-Dietz 1 coal bed; Sp, West Decker Mine spoils. Source of mixing material: SpS, spoils from southern part of West Decker Mine; SpN, spoils from northern part of West Decker Mine; A-Dz1, combined Anderson-Dietz 1 coal bed. Abbreviations: Micromhos, micromhos per centimeter at 25° Celsius; °C, degrees Celsius]

Sample designation	Date	Source of water	Source of mixing material	Mixing ratio by weight (water: material)	Specific conductance, (micromhos)	Onsite pH, units	Temperature (°C)	Calcium (Ca)	Magnesium (Mg)
WR60611*	12-22-81	A-Dz1	---	---	2,680	7.9	21.5	12	4.8
W1A211			SpS	2:1	4,090	7.8	21.5	81	86
W1A212				2:1	4,090	7.8	21.5	78	86
W1A511				5:1	3,300	8.0	21.5	45	48
W1A512				5:1	3,290	8.0	21.5	40	42
WR60612*	01-20-82	A-Dz1	---	---	2,750	8.1	23.0	12	4.9
W1F211			SpN	2:1	3,350	8.3	21.5	16	22
W1F212				2:1	3,450	8.3	25.0	15	22
W1F511				5:1	3,010	8.3	27.5	11	15
W1F512				5:1	3,130	8.3	26.0	12	17
WD22256*	12-15-81	Sp	---	---	3,700	8.4	24.0	16	9.1
W2C111			A-Dz1	1:1	3,330	7.3	23.0	8.6	4.6
W2C112				1:1	3,190	7.1	23.0	8.4	4.4
W2C211				2:1	3,480	7.4	22.5	9.1	4.9
W2C212				2:1	3,500	7.4	22.5	9.3	4.8
W2C511				5:1	3,600	7.6	22.5	10	5.6
W2C512				5:1	3,600	7.7	22.5	10	5.6

*Control sample.

Sodium (Na)	Potas- sium (K)	Silica (SiO ₂)	Bicar- bonate (HCO ₃)	Carbo- nate (CO ₃)	Sulfate (SO ₄)	Chloride (Cl)	Fluo- ride (F)	Dissolved solids, calculated
680	6	8.9	1,480	0	290	16	1.9	1,740
850	14	9.1	1,390	0	1,200	20	1.3	2,940
860	14	9.2	1,370	0	1,200	20	1.4	2,950
740	10	8.2	1,450	0	680	19	1.7	2,270
740	10	8.5	1,440	4	640	18	1.7	2,210
690	6	8.7	1,490	0	290	18	2.1	1,760
870	9	8.3	1,450	58	690	18	2.2	2,410
860	9	8.0	1,220	170	670	18	2.2	2,380
770	7	8.4	1,300	110	470	18	1.9	2,050
800	9	8.2	1,250	130	530	18	1.9	2,150
950	9	11	1,750	26	610	17	1.5	2,510
830	7	10	1,460	0	590	9.1	7.0	2,180
780	6	10	1,310	0	590	6.7	8.8	2,060
860	7	11	1,530	0	600	12	5.1	2,260
840	7	10	1,520	0	600	11	5.1	2,230
890	8	10	1,620	0	600	8.6	2.6	2,340
890	8	10	1,610	14	610	8.9	2.3	2,350

Table 7.--Trace-element concentrations in water from batch-mixing experiments using materials from the West Decker Mine area

[Concentrations are dissolved and concentrations are reported in micrograms per liter. Analyses by Montana Bureau of Mines and Geology. Source of water: A-Dz1, combined Anderson-Dietz 1 coal bed; Sp, West Decker Mine spoils. Source of mixing material: SpS, spoils from southern part of West Decker Mine; SpN, spoils from northern part of West Decker Mine; A-Dz1, combined Anderson-Dietz 1 coal bed. Symbol: <, less than]

Sample designation	Date	Source of water	Source of mixing material	Mixing ratio by weight (water: material)	Aluminum (Al)	Boron (B)	Cadmium (Cd)	Chromium (Cr)	Copper (Cu)	Iron (Fe)
WR60611*	12-22-81	A-Dz1	---	---	<30	<20	<2	<2	<2	<10
W1A211			SpS	2:1	<30	<20	<2	<2	6	<10
W1A212				2:1	<30	<20	<2	<2	8	<10
W1A511				5:1	<30	<30	<2	<2	3	<10
W1A512				5:1	<30	<20	<2	<2	<2	<10
WR60612*	01-20-82	A-Dz1	---	---	<30	40	<2	<2	<2	<10
W1F211			SpN	2:1	<30	40	<2	<2	4	<10
W1F212				2:1	<30	50	<2	<2	7	<10
W1F511				5:1	<30	40	<2	<2	<2	<10
W1F512				5:1	<30	30	<2	<2	3	10
WD22256*	12-15-81	Sp	---	---	30	<20	<2	<2	<2	10
W2C111			A-Dz1	1:1	<30	130	<2	<2	3	20
W2C112				1:1	<30	200	<2	<2	<2	20
W2C211				2:1	30	10	<2	<2	<2	10
W2C212				2:1	<30	120	<2	2	<2	20
W2C511				5:1	<30	40	<2	<2	<2	20
W2C512				5:1	40	<30	<2	<2	<2	20

*Control sample.

Lead (Pb)	Lith- ium (Li)	Manga- nese (Mn)	Molyb- denum (Mo)	Nickel (Ni)	Silver (Ag)	Stron- tium (Sr)	Tita- nium (Ti)	Vana- dium (V)	Zinc (Zn)	Zirco- nium (Zr)
<40	160	8	<20	<10	<2	930	20	<1	310	<3
<40	190	30	<20	<10	<2	2,200	20	<1	<10	<3
<40	190	30	<20	<10	<2	2,200	4	2	<10	<3
<40	170	20	20	<10	<2	1,500	5	<1	<10	<3
<40	170	20	<20	<10	<2	1,200	2	3	<10	<3
<40	160	3	<20	<10	<2	670	2	<1	<10	<3
<40	170	<1	<20	<10	<2	1,100	<1	<1	10	<3
<40	170	<1	<20	<10	<2	1,100	8	<1	<10	<3
<40	160	<1	<20	<10	<2	80	10	<1	<10	<3
<40	160	<1	<20	10	<2	830	10	<1	<10	<3
<40	230	<1	<20	<10	<2	970	<1	<1	80	<3
<40	200	2	<20	<10	<2	710	6	4	<10	<3
<40	190	2	<20	<10	<2	700	<1	<1	<10	<3
<40	210	5	<20	<10	<2	740	<1	<1	<10	<3
<40	200	3	<20	<10	<2	730	<1	<1	<10	<3
<40	220	2	<20	<10	<2	800	1	<1	<10	<3
<40	220	2	<20	<10	<2	840	<1	<1	<10	<3

Table 8.--Records of selected wells in the Big Sky Mine study area

[Well number: Numbering system described in text.
 Site identification number: Unique number consisting of latitude, longitude, and sequence number for the site.
 Altitude of land surface: In feet above sea level.
 Geohydrologic unit: Tft, Tongue River Member of Fort Union Formation, Qal, alluvium; Sp, spoils at Big Sky Mine.

Aquifer zone: R, Rosebud coal bed; Mc, McKay coal bed; super-R, sands above Rosebud coal bed; sub-Mc, sands below McKay coal bed; Sr, spoils from mining of the Rosebud coal bed undifferentiated; Srm, spoils from mining of the Rosebud and McKay coal beds.
 Source of data: BM, Montana Bureau of Mines and Geology; GS, U.S. Geological Survey]

Well number	Site identification number	Other well designation	Altitude of land surface (feet)	Depth of well (feet)	Geo-hydro-logic unit	Aquifer zone	Depth to water below land surface (feet)	Date water level measured (month-day-year)	Source of data
01N41E13CAC01	455011106341701	S-25	3,354	134	Tft	Mc	117.21 117.32 115.53 113.12 106.90	02-04-75 04-01-75 09-09-76 04-12-78 04-03-81	BM
01N41E13CAC02	455011106341702	S-26	3,353	119	Tft	R	87.05 81.07 80.54 80.69 80.71 78.54	02-04-75 06-24-75 12-08-75 09-09-76 04-12-78 04-03-81	BM
01N41E13CDCD01	454956106344901	---	3,290	200	Tft	sub-Mc	107.38 87.12 86.34 85.80 119.50 96.96 107.40	11-09-72 02-02-73 03-06-73 04-10-73 05-17-73 06-22-73 07-18-73	GS
01N41E15DDCD01	454958106364101	BS-49	3,258	40	Sp	---	33.15	09-15-81	BM
01N41E16BABA01	455046106383101	S-18	3,416	248	Tft	Mc	126.18 126.23 125.75 128.49 128.44 127.10 128.72	07-11-74 07-12-74 03-19-76 09-09-76 09-10-76 04-13-78 04-02-81	BM
01N41E16BABA02	455046106383102	S-19	3,417	225	Tft	R	98.98 99.04 98.52 99.07 99.08 98.92 98.52	07-11-74 07-12-74 11-05-74 09-09-76 06-30-77 04-13-78 04-02-81	BM
01N41E17BBBB01	455015106400901	---	3,382	71	Tft	R	8.00	03-23-76	GS
01N41E18ADCC01	455024106402501	S-20	3,466	209	Tft	Mc	141.39 140.01 139.44 138.97	01-10-75 09-09-76 04-13-78 04-02-81	BM
01N41E18ADCC02	455024106402502	S-21	3,465	185	Tft	R	122.03 122.81 122.83 122.77 121.23	01-10-75 09-09-76 12-06-76 04-13-78 04-02-81	BM
01N41E21DADC01	454919106374701	BS-03	3,333	156	Tft	Mc	68.71 68.86 70.45	08-28-75 10-01-75 09-09-76	BM
01N41E21DADC02	454919106374702	BS-04	3,333	121	Tft	R	63.58 64.53 69.59 69.59	08-28-75 04-05-76 09-09-76 09-10-76	BM
01N41E21DBDB01	454921106380601	BS-44	3,343	131	Tft	R	72.24	08-09-81	GS
01N41E21DBDB02	454922106380501	BS-45	3,340	129	Tft	R	71.27	08-09-81	GS
01N41E22AACA01	454946106363701	BS-39	3,300	42	Sp	Srm	Dry Dry Dry	04-06-77 12-13-77 04-03-81	BM

Table 8.--Records of selected wells in the Big Sky Mine study area--Continued

Well number	Site identification number	Other well designation	Altitude of land surface (feet)	Depth of well (feet)	Geo-hydro-logic unit	Aquifer zone	Depth to water below land surface (feet)	Date water level measured (month-day-year)	Source of data
01N41E22AACCO1	454943106364500	---	3,290	53	Tft	---	29.73	08-07-73	GS
01N41E22ABCCO1	454943106370300	Peabody 3	3,390	156	Tft	Mc	107.51	08-08-73	GS
01N41E22ABDDO1	454943106364801	---	3,310	59	Tft	---	33.78	08-07-73	GS
01N41E22ACDCO1	454929106365301	BS-41	3,380	177	Tft	Mc	142.45 150.16 150.09 149.33	04-06-77 12-13-77 03-28-78 03-18-80	BM
01N41E22ACDCO2	454929106365302	BS-42	3,380	146	Tft	R	106.33 106.27 106.89 106.79 106.79 107.68 113.31	04-06-77 05-04-77 11-15-77 12-13-77 03-28-78 04-13-78 04-18-78	BM
01N41E22BAABO1	454954106371000	---	3,370	97	Tft	---	82.92	08-07-73	GS
01N41E22CABDO1	454930106371700	---	3,290	52	Tft	---	20.20	08-21-73	GS
01N41E22CACCO1	454918106372100	---	3,290	54	Tft	---	17.68	08-21-73	GS
01N41E22CCADO1	454914106372401	BS-46	3,258	72	Sp	---	14.90	08-09-81	GS
01N41E22CCADO2	454913106372501	BS-47	3,257	72	Sp	---	14.74	08-09-81	GS
01N41E22CCADO3	454915106372301	BS-48	3,257	20	Sp	---	13.41	08-09-81	GS
01N41E22CDDCO1	454900106365001	BS-50	3,227	35	Sp	---	14.75	09-15-81	BM
01N41E22CDDDO1	454859106365201	BS-51	3,241	30	Qal	---	7.55	09-15-81	BM
01N41E22 DAAO1	454924106363101	BS-40	3,300	60	Sp	Srm	49.53 48.82 45.46	06-04-77 11-15-77 04-03-81	BM
01N41E22DBABO1	454928106365200	Peabody 2	3,370	132	Tft	R	95.11	08-08-73	GS
01N41E23BBBDO1	454949106361800	---	3,250	49	Tft	---	Dry	08-00-73	GS
01N41E23BCACO1	454939106361600	---	3,230	50	Tft	---	43.74	08-00-73	GS
01N41E23BCBDO1	454937106361600	---	3,230	50	Tft	---	43.86	08-00-73	GS
01N41E23BCBDO2	454937106361602	---	3,230	60	Tft	---	43.86	08-00-73	GS
01N41E23BCDCO1	454941106361500	---	3,230	74	Tft	sub-Mc	44.65	08-09-73	GS
01N41E23BCDDO1	454932106361900	---	3,230	59	Tft	---	40.25	08-00-73	GS
01N41E23CBABO1	454929106361701	---	3,220	80	Tft	---	44.17	08-28-75	GS
01N41E23CBBAO1	454929106361801	---	3,220	297	Tft	sub-Mc	145 145	12-13-73 02-27-76	GS GS
01N41E24CAADO1	454924106343801	BS-14	3,159	31	Qal	---	17.67 17.81 16.99 18.18 17.49 17.09 16.92	08-28-75 09-09-76 04-08-77 08-23-77 01-17-78 04-12-78 04-03-81	BM
01N41E24CABCO1	454924106344901	BS-12	3,148	23	Qal	---	11.71 10.63 12.49 13.25 12.93 8.66 12.44	08-28-75 06-24-76 09-09-76 09-20-77 01-17-78 04-12-78 04-03-81	BM

Table 8.--Records of selected wells in the Big Sky Mine study area--Continued

Well number	Site identification number	Other well designation	Altitude of land surface (feet)	Depth of well (feet)	Geo-hydro-logic unit	Aquifer zone	Depth to water below land surface (feet)	Date water level measured (month-day-year)	Source of data
01N41E24CBBC01	454924106350801	BS-13	3,158	22	Qal	---	8.69	08-28-75	BM
							8.93	09-09-76	
							6.40	04-08-77	
							8.99	09-20-77	
							8.07	01-17-78	
							6.46	04-12-78	
7.86	04-03-81								
01N41E24CCBB01	454914106350801	BS-11	3,153	22	Qal	---	12.21	08-28-75	BM
							12.22	09-09-76	
							10.79	04-08-77	
							12.30	09-20-77	
							12.10	01-17-78	
							11.12	04-12-78	
10.87	04-03-81								
01N41E24DDBB01	454913106341400	---	3,150	30	Tft	---	11.85	08-00-73	GS
01N41E25DDBB01	454822106341400	---	3,090	60	Tft	---	32.3	08-02-73	GS
							37.48	08-07-73	
							37.41	08-27-73	
							37.61	08-31-73	
							37.77	09-05-73	
							38.27	09-11-73	
01N41E26BBBB01	454901106362301	BS-01	3,232	220	Tft	sub-Mc	154.00	08-28-75	BM
							152.62	09-09-76	
							152.39	05-03-77	
							154.95	08-24-77	
							153.15	01-17-78	
							153.08	04-03-81	
01N41E26BBBB02	454901106362302	BS-02	3,232	108	Tft	sub-Mc	44.15	08-28-75	BM
							45.08	01-14-76	
							39.65	09-09-76	
							35.66	05-03-77	
							42.26	01-17-78	
							45.18	04-03-81	
01N41E26BCAB01	454848106361600	---	3,190	195	Tft	sub-Mc	23.15	08-02-73	GS
							23.33	08-08-73	
							23.48	08-20-73	
							23.54	08-24-73	
							23.57	08-27-73	
							23.60	08-31-73	
							23.68	09-05-73	
							23.79	09-11-73	
							22.97	02-27-76	
							22.97	04-06-76	
							22.97	04-06-76	
							22.97	04-06-76	
01N41E26CBAA01	454848106361300	---	3,210	35	Tft	---	23.33	08-07-73	GS
01N41E26CBAB01	454836106361501	---	3,210	27	Tft	---	12.19	08-07-73	GS
01N41E26CBAB02	454836106361502	---	3,210	102	Tft	---	22.92	08-07-73	GS
01N41E26CBAC01	454833106361600	---	3,210	66	Tft	---	25.28	08-07-73	GS
01N41E26CBBA01	454835106361900	---	3,200	37	Tft	---	25.02	08-00-73	GS
01N41E27AADD01	454853106363001	S-16	3,223	40	Tft	sub-Mc	24.07	10-23-73	BM
							25.38	11-28-73	
							24.09	09-09-76	
							22.87	03-07-77	
							33.69	01-17-78	
							28.89	04-03-81	
01N41E27AADD02	454853106363002	S-17	3,222	16	Qal	---	9.79	11-28-73	GS
							Muddy	09-09-76	
							9.58	10-23-77	
							Dry	01-17-78	
							Dry	04-03-81	

Table 8.--Records of selected wells in the Big Sky Mine study area--Continued

Well number	Site identification number	Other well designation	Altitude of land surface (feet)	Depth of well (feet)	Geo-hydro-logic unit	Aquifer zone	Depth to water below land surface (feet)	Date water level measured (month-day-year)	Source of data
01N41E27AADD03	454853106363003	BS-43	3,220	14	Qal	---	Dry Dry Dry	04-06-77 01-17-78 04-03-81	BM
01N41E27ABCC01	454853106370001	BS-20	3,274	97	Tft	Mc	48.67 48.65 52.26 51.31 44.95 46.10 46.09 41.06	10-03-75 01-10-76 07-21-76 09-09-76 06-30-77 01-17-78 03-28-78 04-03-81	BM
01N41E27ABCC02	454853106370002	BS-21	3,279	97	Tft	Mc	54.40 56.40 58.43 59.09 58.09 51.35 53.54 52.23 52.20 45.05	10-03-75 04-05-76 06-04-76 07-21-76 09-09-76 06-29-77 07-21-77 01-18-78 03-28-78 04-03-81	BM
01N41E27ABCC03	454853106370003	BS-22	3,278	58	Sp	Sr	50.30 51.31 51.15 50.16 50.56 48.59	10-03-75 07-21-76 09-09-76 10-19-77 01-18-78 04-03-81	BM
01N41E27ACCC01	454837106370001	BS-37	3,265	64	Sp	Sr	53.28 50.55 42.13	04-05-77 12-13-77 04-03-81	BM
01N41E27ADCA01	454841106363601	BS-36	3,255	52	Sp	Srm	49.18 46.19 36.57	06-29-77 01-17-78 04-03-81	BM
01N41E27ADCC01	454852106363401	BS-35	3,255	80	Sp	Srm	34.78 30.97 22.57	04-05-77 01-17-78 04-08-81	BM
01N41E27BADCO1	454853106370901	BS-15	3,325	122	Tft	R	90.75 92.85 91.84 89.01 90.91 90.91 89.23	10-03-75 01-14-76 09-09-76 05-04-77 12-13-77 03-28-78 04-03-81	BM
01N41E27BADCO2	454853106370902	BS-18	3,309	107	Sp	Sr	76.10 77.56 77.12 73.46 76.08 73.52	10-03-75 05-14-76 09-09-76 06-02-77 01-18-78 04-03-81	BM
01N41E27BADCO3	454853106370903	BS-19	3,286	78	Sp	Sr	54.73 55.91 55.43 49.84 52.62 49.87	10-03-75 07-21-76 09-09-76 05-04-77 01-18-78 04-03-81	BM
01N41E27BADCO4	454853106370904	BS-24	3,325	63	Tft	super-R	56.98 57.24 57.32 57.25 57.17	10-03-75 09-09-76 01-24-77 12-13-77 04-03-81	BM

Table 8.--Records of selected wells in the Big Sky Mine study area--Continued

Well number	Site identification number	Other well designation	Altitude of land surface (feet)	Depth of well (feet)	Geo-hydro-logic unit	Aquifer zone	Depth to water below land surface (feet)	Date water level measured (month-day-year)	Source of data
01N41E27BADC05	454853106370905	BS-25	3,330	160	Tft	Mc	105.04	10-03-75	BM
							106.56	06-04-76	
							108.10	07-21-76	
							107.95	09-09-76	
							101.38	06-29-77	
							101.97	12-13-77	
							102.00	03-28-78	
96.72	04-03-81								
01N41E27BDBA01	454848106371601	BS-16	3,331	128	Tft	R	95.04	10-03-75	BM
							97.64	02-11-76	
							97.31	06-04-76	
							100.23	09-09-76	
							94.62	05-04-77	
							96.42	12-13-77	
							96.39	03-28-78	
94.83	04-03-81								
01N41E27BDBA02	454848106371602	BS-17	3,332	134	Tft	R	101.77	08-28-75	BM
							103.87	02-11-76	
							102.85	09-09-76	
							100.72	05-04-77	
							102.49	12-13-77	
							102.79	03-28-78	
							100.97	04-03-81	
01N41E27BDBA03	454848106371603	BS-23	3,335	76	Tft	super-R	67.96	08-28-75	BM
							68.24	09-09-76	
							68.37	12-13-77	
							68.63	04-03-81	
01N41E27CAAC01	454832106370901	BS-30	3,350	155	Tft	R	129.59	04-05-77	BM
							129.04	07-21-77	
							128.80	08-24-77	
							128.84	10-18-77	
							128.81	03-28-78	
							124.64	04-03-81	
01N41E27DAAC01	454832106363201	S-14	3,248	51	Tft	Mc	41.32	09-09-73	BM
							47.01	09-25-73	
							46.35	10-23-73	
							46.47	11-28-73	
							47.01	02-04-74	
							47.01	05-23-74	
							47.01	06-05-74	
							46.59	02-05-75	
							44.69	01-13-76	
							43.50	04-05-76	
							34.74	07-21-77	
							32.71	01-17-78	
							32.71	03-28-78	
							27.75	04-03-81	
01N41E27DAAC02	454832106363202	S-15	3,248	34	Sp	Sr	Dry	10-23-73	GS
							Dry	11-28-73	
							Dry	09-09-76	
							Dry	01-17-78	
27.80	04-03-81	BM							
01N41E27DABB01	454835106364101		TW-02	3,265	Sp	Srm	Dry	07-29-76	BM
							Dry	03-07-77	
							Dry	04-03-81	
01N41E27DABB02	454835106364102	BS-29	3,275	144	Sp	Srm	65.91	08-19-76	BM
							53.90	01-17-78	
							45.70	04-03-81	
01N41E27DACA01	454827106363901	TW-01	3,259	75	Sp	Sr	55.25	03-19-76	BM
							53.77	06-25-76	
							55.25	08-19-76	
							32.19	01-22-81	
01N41E27DADC01	454827106363201	BS-34	3,250	70	Sp	Sr	43.11	04-05-77	BM
							37.37	01-17-78	
							27.86	04-03-81	

Table 8.--Records of selected wells in the Big Sky Mine study area--Continued

Well number	Site identification number	Other well designation	Altitude of land surface (feet)	Depth of well (feet)	Geo-hydro-logic unit	Aquifer zone	Depth to water below land surface (feet)	Date water level measured (month-day-year)	Source of data
01N41E27DBAD01	454832106364801	BS-27	3,265	88	Sp	Sr	55.74 43.01 36.03	08-19-76 01-17-78 04-03-81	BM
01N41E27DBDA01	454828106365501	BS-38	3,270	84	Sp	Srm	57.94 53.87 46.96	04-05-77 01-17-78 04-03-81	BM
01N41E27DBDC01	454827106365101	BS-28	3,274	106	Sp	Sr	64.86 52.00 45.24	08-19-76 01-17-78 04-03-81	BM
01N41E27DCCA01	454815106365501	BS-31	3,350	145	Tft	R	138.88 138.06 138.06 137.99 134.17	04-05-77 08-24-77 10-18-77 03-28-78 04-03-81	BM
01N41E27DDAC01	454818106363401	BS-26	3,265	55	Sp	---	Dry Dry 53.51 49.71	07-28-76 09-11-76 03-28-78 04-03-81	BM
01N41E27DDAC02	454818106363402	BS-32	3,265	100	Tft	Mc	59.12 53.54 44.22	04-05-77 01-17-78 04-03-81	BM
01N41E27DDBC01	454818106364101	BS-33	3,270	100	Sp	Sr	45.21 36.57	03-28-78 04-03-81	BM
01N41E28BDCB01	454840106383301	BS-07	3,340	168	Tft	Mc	86.64 86.61 88.29 89.83 89.80 87.60	08-28-75 03-19-76 09-09-76 07-28-77 10-19-77 04-03-81	BM
01N41E28BDCB02	454840106383302	BS-08	3,341	131	Tft	R	72.27 72.24 74.03 74.77 73.87	08-28-75 11-05-75 09-09-76 10-19-77 04-03-81	BM
01N41E29BBAA01	454901106395501	BS-05	3,405	209	Tft	Mc	120.47 120.05 120.76 120.93 120.54 120.21	08-28-75 03-19-76 09-09-76 10-19-77 11-16-77 04-03-81	BM
01N41E29BBAA02	454901106395502	BS-06	3,406	177	Tft	R	92.06 92.59 93.06 93.34 92.37	08-28-75 10-03-75 09-09-76 11-16-77 04-07-81	BM
01N41E30BBCD01	454852106411700	---	3,330	90	Tft	R	30.0	09-07-73	GS
01N41E33BCCB01	454751106385400	---	3,190	65	Tft	---	21.97	09-05-73	GS
01N41E35BCDB01	454748106361301	BS-09	3,294	105	Tft	Mc	Dry Dry 103.84 103.64	08-28-75 09-09-76 10-16-79 04-03-81	BM
01N41E35BCDB02	454748106361302	BS-10	3,294	72	Tft	R	Dry Dry 71.82 Dry	08-28-75 09-09-76 08-15-79 11-07-80	BM
01N41E36DCBA01	454732106342801	KCSE-3	3,200	150	Tft	Mc	130.45	11-20-80	GS

Table 8.--Records of selected wells in the Big Sky Mine study area--Continued

Well number	Site identification number	Other well designation	Altitude of land surface (feet)	Depth of well (feet)	Geo-hydro-logic unit	Aquifer zone	Depth to water below land surface (feet)	Date water level measured (month-day-year)	Source of data
01N42E32DADD01	454732106313100	---	2,990	80	Tft	sub-Mc	31.56	08-00-73	GS
01N42E33ADBC01	454753106303201	---	2,970	42	Tft	---	20.74 26.32 19.42 20.04 19.24 19.75 20.70	09-28-72 02-01-73 03-06-73 04-10-73 05-09-73 06-22-73 07-06-79	GS
01N42E33BDCA01	454719106310000	---	2,990	91	Tft	sub-Mc	57.0	08-00-73	GS
01S42E03BBDD01	454708106322400	---	2,990	210	Tft	---	13.09	08-00-73	GS
01S42E03CBBB01	454653106323201	---	3,010	---	Qa1	---	15.17	08-15-73	GS
01S42E04DADC01	454642106324000	---	3,010	---	Tft	---	22.42	08-01-73	GS
01S42E04DBCC01	454640106331001	---	3,000	150	Tft	---	18.60	07-05-79	GS
01S42E04DCAA01	454639106330701	---	3,010	38	Qa1	---	26.56	08-01-73	GS
01S42E04DCAA02	454640106330701	---	3,010	40	Qa1	---	22.20	08-01-73	GS
01S42E05ADBB01	454705106340800	---	3,070	135	Tft	---	60.0 60.04	08-02-73 02-27-76	GS BM

Table 9 begins on
next page

Table 9.--Common-constituent concentrations in water from selected wells in the Big Sky Mine study area

[Constituents are dissolved and concentrations are reported in milligrams per liter. Analyses by Montana Bureau of Mines and Geology. Aquifer zone: R, Rosebud coal bed; Mc, McKay coal bed; sub-Mc, sands below McKay coal bed; super-R, sands above Rosebud coal bed; Su, spoils from mining, undifferentiated; Sr, spoils from mining of the Rosebud coal bed; Srm, spoils from mining of the Rosebud and McKay coal beds; Qal, alluvium. Source of data: BM, Montana Bureau of Mines and Geology; GS, U.S. Geological Survey. Abbreviations: °C, degrees Celsius; micromhos, micromhos per centimeter at 25° Celsius; <, less than]

Well number	Date of sample (month-day-year)	Aquifer zone	Specific conductance (micromhos)	Laboratory pH, units	Temperature (°C)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)
01N41E13CDCD01	07-18-73	sub-Mc	2,150	7.64	16.0	150	180	130	8
01N41E16BABA01	07-12-74	Mc	1,310	8.25	--	45	41	200	6
01N41E16BABA02	07-12-74 05-13-75	R	1,250 1,230	8.00 7.73	-- 13.5	47 73	83 68	110 120	5 5
01N41E17BBBB01	03-23-76	R	205	7.22	6.5	6.5	11	20	2
01N41E21DADC01	10-01-75	Mc	3,060	7.85	--	200	170	350	11
01N41E21DADC02	04-05-76	R	1,790	7.67	14.0	150	160	62	5
01N41E21DBDB01	08-10-81	R	3,230	7.36	14.5	310	350	140	7
01N41E21DBDB02	08-11-81	R	3,330	7.38	15.5	310	350	130	8
01N41E22ACDC01	03-28-78	Mc	3,290	7.49	10.0	210	160	420	18
01N41E22ACDC02	07-21-77 03-28-78	R	2,030 1,860	7.77 7.17	16.5 12.0	180 140	180 170	61 70	7 5
01N41E22CCAD01	08-12-81	Su	4,100	7.63	14.0	370	10	170	14
01N41E22CCAD02	08-13-81	Su	4,300	7.63	14.0	400	440	190	16
01N41E22 DAA01	10-19-77 03-28-78 08-15-79 06-04-80	Srm	1,780 1,700 2,350 1,860	7.65 7.25 7.91 7.27	14.0 13.0 14.0 12.8	130 95 100 64	170 170 320 260	59 65 96 93	6 5 5 6
01N41E23BCDC01	08-09-73	sub-Mc	2,800	8.36	19.0	110	240	210	9
01N41E23CBBA01	02-27-76	sub-Mc	2,400	8.14	--	21	13	520	4
01N41E24CAAD01	08-28-75	Qal	3,660	8.06	10.0	260	250	420	10
01N41E24CABC01	08-28-75	Qal	2,620	7.94	11.0	130	250	170	6
01N41E24CBBC01	08-28-75	Qal	3,280	8.05	13.0	210	340	220	8
01N41E24CCBB01	08-28-75	Qal	2,780	7.91	11.0	140	220	280	8
01N41E26BCAB01	02-27-76 04-06-76	sub-Mc	2,950 2,960	7.73 7.96	-- --	150 160	330 320	150 150	10 9
01N41E27AADD01	09-25-73 02-04-74 06-06-74 02-05-75 08-15-79 06-05-80	sub-Mc	3,550 3,800 3,710 3,820 3,700 3,710	7.83 7.74 7.48 7.77 7.66 7.65	-- -- -- 8.0 11.0 10.5	270 300 330 270 280 280	360 380 350 410 390 390	190 210 190 210 200 210	4 4 4 5 4 5
01N41E27AADD02	02-04-74	Qal	7,240	8.17	--	400	920	500	8
01N41E27ABCC01	01-10-76 03-28-78 05-29-80	Mc	2,910 3,080 3,150	7.79 7.39 7.65	-- 13.5 13.0	220 250 280	240 250 260	220 230 250	15 10 12
01N41E27ABCC02	04-05-76 06-04-76 07-21-77 03-28-78 05-29-80	Mc	3,060 3,040 3,010 3,060 3,130	7.75 7.06 7.28 7.15 7.37	12.5 11.0 11.5 11.0 11.0	240 230 250 250 300	230 230 240 260 290	240 220 220 200 210	9 9 10 9 11

Bicar- bonate (HCO ₃)	Carbo- nate (CO ₃)	Sul- fate (SO ₄)	Chlo- ride (Cl)	Fluo- ride (F)	Silica (SiO ₂)	Dis- solved solids, calcu- lated	Nitrate as (N)	Source of data
560	0	930	6.0	0.2	13	1,980	0.20	GS
440	0	340	5.0	.2	10	873	.63	BM
430	0	340	6.4	.1	12	814	.05	BM
550	0	270	4.1	.1	14	827	.14	
90	0	23	4.0	.3	1.1	111	.05	GS
630	0	1,400	11	.3	12	2,500	<.02	BM
590	0	680	5.4	.2	16	1,370	.24	BM
930	0	1,700	15	.2	20	3,020	.02	GS
930	0	1,700	15	.3	20	2,980	.04	GS
520	0	1,600	10	.4	14	2,710	.08	BM
220	0	930	150	.4	14	1,620	2.7	BM
570	0	700	5.0	.2	19	1,390	.06	
720	0	2,500	13	1.5	11	3,830	.07	GS
710	0	2,700	11	2.0	11	4,070	.04	GS
480	0	730	8.5	.4	15	1,350	1.9	BM
520	0	610	10	.4	16	1,230	2.4	
730	0	1,100	11	.3	14	2,010	1.2	
490	0	990	7.5	.5	12	1,670	.02	
240	5	1,400	13	.1	16	2,270	2.4	GS
450	0	790	11	1.0	7.5	1,590	.60	GS
590	0	2,000	17	.1	10	3,290	1.1	BM
530	0	1,200	17	.2	9.7	2,090	4.7	BM
440	0	1,900	14	.2	18	2,960	.68	BM
460	0	1,400	11	.2	7.9	2,340	1.8	BM
600	0	1,500	13	.2	17	2,450	.59	BM
590	0	1,400	12	.2	18	2,390	.73	
410	0	2,100	16	.2	13	3,190	2.3	BM
440	0	2,300	13	.2	16	3,480	4.5	
480	3	2,100	18	.2	15	3,270	4.5	
460	0	2,300	15	.2	16	3,470	4.7	
590	0	2,200	17	.2	17	3,380	3.5	
620	0	2,200	15	.7	19	3,390	1.0	
330	0	5,400	33	.2	15	7,470	7.2	BM
580	0	1,500	12	.2	14	2,520	.02	BM
710	0	1,500	15	.2	17	2,640	.03	
700	0	1,600	16	.1	17	2,790	.45	
710	0	1,400	11	.2	14	2,500	.02	BM
700	0	1,400	1.6	.1	14	2,420	.04	
740	0	1,400	19	.2	15	2,520	.40	
740	0	1,500	11	.2	18	2,600	.29	
790	0	1,600	82	.1	18	2,880	.45	

Table 9.--Common-constituent concentrations in water from selected wells
in the Big Sky Mine study area--Continued

Well number	Date of sample (month-day-year)	Aquifer zone	Specific conduc- tance, (micro- mhos)	Labora- tory pH, units	Temper- ature (°C)	Cal- cium (Ca)	Magne- sium (Mg)	Sodium (Na)	Potas- sium (K)
01N41E27ABCC03	04-05-76	Sr	7,480	7.55	12.0	430	730	820	12
	06-04-76		7,490	6.83	11.5	450	690	790	13
	02-19-77		7,070	8.05	11.0	390	680	780	12
	07-21-77		7,120	7.09	12.0	440	690	750	12
	03-28-78		7,030	7.0	11.5	440	710	730	12
	08-15-79		7,660	7.81	14.0	420	730	850	13
	05-29-80		10,800	5.71	11.0	380	940	1,600	17
01N41E27ACCC01	03-28-78	Sr	6,130	7.09	10.0	460	690	420	21
	06-05-80		4,510	7.18	10.0	300	400	230	15
01N41E27ADCA01	03-28-78	Su	5,110	6.72	12.5	570	610	130	23
	05-28-80		5,330	7.19	12.0	440	730	130	18
01N41E27ADCC01	03-28-78	Srm	3,750	6.96	12.0	410	330	160	15
	05-29-80		4,080	7.14	13.0	480	370	140	17
01N41E27BADC01	03-28-78	R	4,010	7.05	12.0	400	360	230	9
	05-28-80		4,020	7.46	12.0	290	360	230	11
01N41E27BADC02	03-28-78	Sr	3,340	7.22	14.0	310	300	200	12
	05-29-80		3,450	7.45	13.0	260	310	210	13
01N41E27BADC03	04-05-76	Sr	4,390	7.66	14.5	380	460	180	22
	07-21-77		4,340	7.24	14.5	330	470	230	19
	03-28-78		4,300	7.03	14.0	370	490	200	21
	08-15-79		4,380	7.35	14.0	210	490	220	20
	05-29-80		4,200	7.08	13.0	330	480	210	22
01N41E27BADC04	05-29-80	super-R	825	8.2	16.0	62	60	17	4
01N41E27BADC05	06-04-76	Mc	3,990	7.35	12.0	260	160	430	12
	03-28-78		3,670	7.48	12.0	290	250	370	11
	06-05-80		3,620	7.48	12.0	260	280	360	12
01N41E27BDBA01	06-04-76	R	3,330	7.25	12.0	300	270	190	9
	03-28-78		2,570	7.1	12.5	230	210	150	7
01N41E27BDBA02	03-28-78	R	4,180	7.07	12.0	400	390	250	10
01N41E27BDBA03	05-29-80	super-R	1,530	7.66	11.0	120	120	26	4
01N41E27CAAC01	07-21-77	R	4,500	7.2	13.0	510	490	140	9
	03-28-78		4,480	7.09	12.5	500	470	140	9
	06-05-80		4,590	7.25	12.0	350	450	290	11
01N41E27DAAC01	09-25-73	Mc	4,210	7.76	--	350	460	170	10
	02-04-74		3,950	7.66	--	350	430	170	9
	05-23-74		4,140	7.40	12.0	420	420	170	9
	02-05-75		4,250	7.68	9.0	370	460	180	9
	01-13-76		4,280	7.33	9.0	440	480	180	9
	04-05-76		4,300	7.59	12.5	430	450	170	9
	07-21-77		2,910	7.24	13.0	20	270	120	8
	03-28-78		3,000	7.17	12.0	280	280	120	10
	05-30-80		3,980	7.26	12.0	420	410	150	13
01N41E27DAAC02	06-04-80	Sr	6,220	7.29	12.0	340	900	360	13
01N41E27DABB02	03-28-78	Srm	3,450	7.03	12.5	370	330	120	18
	08-15-79		3,390	7.73	13.0	280	350	110	19
01N41E27DACA01	04-13-76	Sr	3,770	7.75	10.5	410	360	120	16
	03-28-78		3,720	6.84	11.0	390	350	150	16
	06-04-80		3,750	7.06	12.0	320	350	140	18

Bicar- bonate (HCO ₃)	Carbo- nate (CO ₃)	Sul- fate (SO ₄)	Chlo- ride (Cl)	Fluo- ride (F)	Silica (SiO ₂)	Dis- solved solids, calcu- lated	Nitrate as (N)	Source of data
640	0	4,800	75	0.2	11	7,170	0.04	BM
640	0	4,900	68	.2	11	7,220	.04	
520	0	4,700	71	.4	13	6,910	1.6	
670	0	4,600	66	.3	13	6,860	.36	
720	0	4,700	73	.3	15	7,050	1.2	
730	0	5,000	93	.1	12	7,510	6.4	
1,040	0	6,900	180	4.0	14	10,600	.45	
720	0	4,100	37	.3	15	6,140	.03	BM
550	0	2,300	28	.3	12	3,590	1.3	
1,590	0	2,900	15	.2	17	5,010	.05	BM
1,150	0	3,200	52	.1	15	5,190	<.02	
770	0	2,000	14	.1	14	3,370	.03	BM
750	0	2,300	32	2.5	12	3,700	<.02	
1,040	0	2,000	11	.1	17	3,560	.38	BM
690	0	2,000	24	.1	15	3,270	1.8	
780	0	1,700	10	.2	15	2,960	.04	BM
880	0	1,600	24	.1	14	2,830	.45	
730	0	2,400	28	.2	13	3,880	15	BM
740	0	2,300	57	.1	14	3,800	44	
790	0	2,600	23	.2	13	4,150	5.4	
790	0	2,300	22	.1	12	3,680	6.7	
680	0	2,500	30	.1	13	3,960	.90	
350	0	120	2.3	.2	13	452	.02	BM
690	0	1,700	25	.3	10	2,920	<.02	BM
690	0	1,900	13	.2	16	3,220	1.7	
620	0	2,000	2.4	.1	16	3,270	.09	
820	0	1,700	7.7	.1	13	2,760	<.02	BM
730	0	1,100	7.8	.3	15	2,090	.42	
540	0	2,500	15	.1	15	3,890	.44	BM
390	0	470	11	.1	12	953	.02	BM
970	0	2,600	25	.1	16	4,300	.06	BM
1,000	0	2,600	25	<.1	18	4,250	.04	
770	0	2,500	31	1.2	15	4,010	.11	
540	0	2,700	24	.2	12	3,960	.23	BM
530	0	2,500	23	.2	14	3,710	.29	
710	0	2,400	25	.4	16	3,780	.29	
580	0	2,600	23	.2	13	3,880	.09	
770	0	2,600	23	.3	14	4,080	.32	
740	0	2,500	25	.3	14	3,990	.03	
640	0	1,400	34	.2	16	2,470	.03	
670	0	1,500	22	.2	17	2,540	.39	
960	0	2,100	57	.1	14	3,670	.23	
1,110	0	4,300	21	.6	20	6,450	<.02	BM
830	0	1,800	32	.2	20	3,090	.03	BM
720	0	1,800	12	.1	17	2,900	<.02	
860	0	2,000	27	.1	9.6	3,320	.02	BM
810	0	2,000	20	.2	11	3,360	1.4	
540	0	2,000	19	.1	11	3,130	2.1	

Table 9.--Common-constituent concentrations in water from selected wells
in the Big Sky Mine study area--Continued

Well number	Date of sample (month-day-year)	Aquifer zone	Specific conductance, (micro-mhos)	Laboratory pH, units	Temperature (°C)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)
01N41E27DADC01	07-21-77	Sr	3,720	7.08	13.5	370	400	130	15
	03-28-78		3,690	7.05	13.0	340	380	130	14
	05-28-80		3,900	6.67	13.0	420	400	120	17
01N41E27DBAD01	02-04-77	Sr	3,390	7.64	13.0	340	310	120	17
	03-28-78		3,370	7.04	12.5	320	340	120	18
	06-04-80		3,200	6.74	13.0	240	310	120	17
01N41E27DBDA01	03-28-78	Srm	3,480	6.90	13.0	360	330	120	21
01N41E27DBDC01	11-19-76	Sr	3,230	7.42	10.0	320	300	110	13
	02-03-77		3,270	7.75	9.0	300	310	110	15
	07-21-77		3,250	7.09	11.5	330	310	120	17
	03-28-78		3,180	6.91	11.0	310	300	110	16
	08-15-79		2,520	7.88	12.0	230	220	90	13
	06-03-80		2,910	6.66	11.5	260	260	110	15
01N41E27DCCA01	03-28-78	R	4,890	6.99	12.5	450	480	280	9
	06-05-80		3,950	7.28	11.5	350	430	150	9
01N41E27DDAC01	06-04-80	Su	2,890	7.10	12.0	160	220	50	23
01N41E27DDAC02	03-28-78	Mc	3,630	6.96	12.0	360	340	140	15
	06-05-80		4,590	7.15	12.0	450	390	140	15
01N41E27DDBC01	03-28-78	Sr	3,650	6.93	12.0	370	340	140	16
	05-28-80		4,150	7.02	12.0	440	430	130	20
01N41E35BCDB01	08-15-79	Mc	2,400	7.36	14.0	83	31	690	21
01N42E33ADBC01	09-28-72	--	3,490	8.16	10.0	110	120	620	12
	07-06-79		3,680	8.33	10.0	120	110	630	10
01S42E04DBCC01	07-05-79	--	2,320	8.35	10.5	20	11	480	5
01S42E04DCAA01	08-01-73	Qa1	5,250	8.33	11.5	87	260	870	20
01S42E04DCAA02	08-01-73	Qa1	4,500	8.60	13.0	53	160	750	27
01S42E05ADBB01	02-27-76	--	4,350	8.10	--	62	100	840	6
	06-02-76		5,850	--	13.0	110	180	1,000	12

Bicar- bonate (HCO ₃)	Carbo- nate (CO ₃)	Sul- fate (SO ₄)	Chlo- ride (Cl)	Fluo- ride (F)	Silica (SiO ₂)	Dis- solved solids, calcu- lated	Nitrate as (N)	Source of data
880	0	2,000	17	<0.1	12	3,350	0.30	BM
870	0	1,900	15	<.1	15	3,270	.04	
900	0	2,100	48	.1	13	3,590	<.01	
770	0	1,700	15	.1	10	2,890	.02	BM
760	0	1,800	20	.1	13	2,960	.15	
660	0	1,500	8.1	.2	11	2,510	.01	
780	0	1,800	17	.2	9.7	3,070	3.0	BM
760	0	1,500	46	.1	9.8	2,710	.03	BM
770	0	1,600	23	.5	10	2,750	<.02	
750	0	1,600	48	.1	9.8	2,850	.03	
700	0	1,600	13	.2	11	2,740	.10	
490	0	1,200	7.0	.1	8.0	2,030	1.2	
470	0	1,500	8.2	.2	11	2,420	<.01	
870	0	2,900	38	.2	18	4,620	.68	BM
630	0	2,400	8.5	.1	18	3,650	.01	
780	0	800	12	.1	12	1,670	.08	BM
720	0	1,900	24	<.1	16	3,190	.10	BM
630	0	2,400	26	.1	12	3,790	<.23	
790	0	1,900	15	.1	12	3,200	.03	BM
830	0	2,400	16	.1	13	3,860	4.5	
600	0	1,300	22	.2	8.5	2,400	1.1	BM
520	0	1,600	16	.5	60	2,840	.02	GS
510	5	1,700	12	.5	28	2,880	.33	
420	4	700	5.7	.6	7.6	1,490	.35	GS
440	24	1,900	27	.4	24	3,440	6.1	GS
560	20	2,500	33	.5	25	4,440	8.9	GS
720	0	1,700	14	.7	6.9	3,080	1.9	GS
710	0	2,400	14	.4	8.0	4,200	3.3	

Table 10.--Trace-element concentrations in water from selected wells in the Big Sky Mine study area

[Constituents are dissolved and concentrations are reported in micrograms per liter. Analyses by Montana Bureau of Mines and Geology. Aquifer zone: R, Rosebud coal bed; Mc, McKay coal bed; sub-Mc, sands below McKay coal bed; super-R, sands above Rosebud coal bed; Su, spoils from mining undifferentiated; Sr, spoils from mining of the Rosebud coal bed; Srm, spoils from mining of the Rosebud and McKay coal beds; Qal, alluvium. Source of data: BM, Montana Bureau of Mines and Geology; GS, U.S. Geological Survey. Symbol: <, less than]

Well number	Date of sample (month-day-year)	Aquifer zone	Aluminum (Al)	Antimony (Sb)	Arsenic (As)	Beryllium (Be)	Boron (B)	Cadmium (Cd)	Chromium (Cr)	Copper (Cu)	Iron (Fe)
01N41E13CDCD01	07-18-73	sub-Mc	--	--	--	--	--	--	--	--	2,900
01N41E21DADC01	10-01-75	Mc	<50	<200	<2	<10	460	<10	<10	10	20
01N41E21DADC02	04-05-76	R	<50	<200	3	<10	200	<10	<10	<10	540
01N41E21DBDB01	08-10-81	R	<30	--	--	--	280	<2	<2	22	1,000
01N41E21DBDB02	08-11-81	R	<30	--	--	--	320	13	30	69	910
01N41E22CCAD01	08-12-81	Su	500	--	--	--	730	30	60	130	310
01N41E22CCAD02	08-13-81	Su	500	--	--	--	630	22	60	130	410
01N41E22DAA 01	10-19-77 03-28-78 08-15-79 06-04-80	Srm	-- -- -- --	-- -- -- --	-- -- -- --	-- -- -- --	-- -- 240 --	-- -- -- --	-- -- -- --	-- -- -- --	40 30 10 120
01N41E23BCDC01	08-09-73	sub-Mc	--	--	--	--	--	--	--	--	260
01N41E23CBBA01	02-27-76	sub-Mc	--	--	--	--	--	--	--	--	10
01N41E24CAAD01	08-28-75	Qal	--	--	--	--	--	--	--	--	20
01N41E24CABC01	08-28-75	Qal	--	--	--	--	--	--	--	--	10
01N41E24CCBB01	08-28-75	Qal	--	--	--	--	--	--	--	--	10
01N41E26BCAB01	02-27-76 04-06-76	sub-Mc	-- 50	-- 0	-- <2	-- <10	-- 330	-- <20	-- <20	-- <20	30 20
01N41E27AADD01	08-15-79 06-05-80	sub-Mc	-- 100	-- --	-- --	-- --	770 900	-- <10	-- <20	-- <30	<10 30
01N41E27ABCC01	10-01-75 05-29-80	Mc	50 --	<200 --	<2 --	<10 --	550 --	<10 --	<10 --	10 --	30 20
01N41E27ABCC02	04-05-76 05-29-80	Mc	<50 --	<200 --	-- --	<10 --	380 --	<10 --	<10 --	10 --	1,500 20
01N41E27ABCC03	04-05-76 06-04-76 02-19-77 07-21-77 03-28-78 08-15-79 05-29-80	Sr	<50 <50 -- 100 -- -- --	<200 200 -- 600 -- -- --	<2 -- <2 <2 -- -- --	<10 <10 -- <10 -- -- --	950 900 -- -- -- 590 --	10 20 -- 30 -- -- --	20 60 -- 30 -- -- --	20 20 -- 20 -- -- --	770 20 80 60 60 20 30
01N41E27ACCC01	03-28-78 06-05-80	Sr	-- 400	-- --	-- --	-- --	-- 970	-- <10	-- 30	-- 40	70 20
01N41E27ADCA01	03-28-78 05-28-80	Su	-- --	-- --	-- --	-- --	-- --	-- --	-- --	-- --	100 20
01N41E27ADCC01	03-28-78 05-29-80	Srm	-- 100	-- 400	-- <1	-- --	-- 560	-- <10	-- <30	-- 60	50 460
01N41E27BADC01	05-28-80	R	--	--	--	--	--	--	--	--	20
01N41E27BADC02	03-28-78 05-29-80	Sr	-- --	-- --	-- --	-- --	-- --	-- --	-- --	-- --	40 20
01N41E27BADC03	04-05-76 07-21-77 03-28-78 08-15-79 05-29-80	Sr	<50 70 -- -- --	<200 500 -- -- --	<2 <2 -- -- --	<10 <10 -- -- --	240 -- -- -- --	<10 20 -- -- --	10 20 -- -- --	10 20 -- -- --	50 50 40 10 20

Lead (Pb)	Lithium (Li)	Manganese (Mn)	Mercury (Hg)	Nickel (Ni)	Selenium (Se)	Silver (Ag)	Strontium (Sr)	Tin (Sn)	Zinc (Zn)	Source of data
--	--	210	--	--	--	--	--	--	--	GS
70	50	70	0.5	30	<2	<10	12,300	170	130	BM
100	30	240	--	40	<2	<10	2,500	210	10	BM
<40	30	370	--	<10	--	<2	5,100	--	70	GS
60	60	360	--	30	--	29	4,500	--	110	GS
--	110	490	--	100	--	75	8,100	--	30	GS
--	110	490	--	100	--	76	9,200	--	30	GS
<50	30	40	--	--	--	--	--	--	--	BM
<50	50	340	--	--	--	--	--	--	270	
<40	10	0	--	--	--	--	--	--	--	
--	--	<10	--	--	1	--	--	--	--	
--	--	130	--	--	--	--	--	--	--	GS
--	30	30	--	--	--	--	--	--	--	GS
--	--	10	--	--	--	--	--	--	--	BM
--	--	<10	--	--	--	--	--	--	--	BM
--	--	20	--	--	--	--	--	--	--	BM
--	50	<10	--	--	--	--	--	--	--	BM
<10	50	10	--	50	2	<20	3,800	350	<20	
80	30	<10	--	--	--	--	--	--	--	BM
<40	60	<10	--	<10	<1	10	6,300	--	<10	
60	50	180	<.5	40	<2	<10	9,000	350	40	BM
<40	60	<10	--	--	<1	--	--	--	--	
110	60	250	--	60	<2	<10	7,200	280	10	BM
<40	60	40	--	--	<1	--	--	--	--	
200	80	2,800	--	110	<2	10	6,500	680	40	BM
130	80	2,000	.5	60	--	<10	6,200	840	50	
<10	70	1,500	<.5	--	<2	--	15,900	4,900	--	
10	70	2,600	--	120	<2	10	6,200	1,300	90	
170	60	2,500	--	--	--	--	--	--	--	
160	50	<10	--	--	--	--	--	--	--	
<40	90	2,000	--	--	<1	--	--	--	--	
190	70	5,700	--	--	--	--	--	--	--	BM
130	70	950	--	20	<1	20	7,100	--	<10	
150	50	6,900	--	--	--	--	--	--	--	BM
<40	50	210	--	--	<1	--	--	--	--	
100	80	830	--	--	--	--	--	--	--	BM
130	70	1,200	.5	100	<1	10	11,800	<10	70	
<40	60	<10	--	--	<1	--	--	--	--	BM
80	70	470	--	--	--	--	--	--	--	BM
50	90	180	--	--	<1	--	--	--	--	
130	90	1,600	--	120	<2	10	6,600	460	30	BM
<10	80	1,300	--	100	<2	10	4,200	1,000	300	
130	80	660	--	--	--	--	--	--	--	
110	50	10	--	--	--	--	--	--	--	
<40	90	1,600	--	--	<1	--	--	--	--	

Table 10.--Trace-element concentrations in water from selected wells in the Big Sky Mine study area--Continued

Well number	Date of sample (month-day-year)	Aquifer zone	Aluminum (Al)	Antimony (Sb)	Arsenic (As)	Beryllium (Be)	Boron (B)	Cadmium (Cd)	Chromium (Cr)	Copper (Cu)	Iron (Fe)
01N41E27BADCO4	05-29-80	super-R	--	--	--	--	--	--	--	--	10
01N41E27BADCO5	06-05-80	Mc	100	--	--	--	390	<10	10	20	20
01N41E27BDBA03	05-29-80	super-R	--	--	--	--	--	--	--	--	<10
01N41E27CAAC01	06-05-80	R	200	--	--	--	570	<10	30	40	20
01N41E27DAAC01	04-05-76 05-30-80	Mc	<50 --	<20 --	-- --	<10 --	380 --	<10 --	20 --	<10 --	1,200 10
01N41E27DABB02	03-28-78 08-15-79	Srm	-- --	-- --	-- --	-- --	-- 270	-- --	-- --	-- --	210 <10
01N41E27DACA01	04-13-76 03-28-78 06-04-80	Sr	-- -- 100	-- -- --	-- -- --	-- -- --	-- -- 360	-- -- <10	-- -- 20	-- -- 30	30 30 20
01N41E27DADC01	07-21-77 03-28-78 05-28-80	Sr	-- -- 400	-- -- 400	-- -- <1	-- -- --	-- -- 590	-- -- 20	-- -- 50	-- -- 80	20 80 100
01N41E27BDAD01	02-04-77 03-28-78 06-04-80	Sr	50 -- 300	300 -- --	<2 -- --	<10 -- --	-- -- 390	<10 -- 10	20 -- 30	10 -- 40	320 30 280
01N41E27DBDA01	03-28-78	Srm	--	--	--	--	--	--	--	--	30
01N41E27DBDC01	11-19-76 02-03-77 07-21-77 03-28-78 08-15-79 06-03-80	Sr	<50 <50 80 -- -- 200	<200 300 400 -- -- 300	<2 <2 <2 -- -- <1	<10 <10 <10 -- -- --	600 -- -- -- 140 320	20 10 20 -- -- <10	<10 20 20 -- -- 20	20 10 20 -- -- 40	30 380 240 30 <10 380
01N41E27DCCA01	06-05-80	R	200	--	--	--	430	<10	30	30	20
01N41E27DDAC01	06-04-80	Su	<30	--	--	--	310	<10	<10	10	20
01N41E27DDAC02	06-05-80	Mc	200	--	--	--	530	<10	20	40	1,100
01N41E27DDBC01	03-28-78 05-28-80	Sr	-- --	-- --	-- --	-- --	-- --	-- --	-- --	-- --	30 10
01N41E35BCDB01	08-15-79	Mc	--	--	--	--	60	--	--	--	<10
01N42E33ADBC01	09-28-72 07-06-79	--	-- --	-- --	-- --	-- --	-- 720	-- --	-- --	-- --	3,100 3,200
01S42E04DBCC01	07-05-79	--	--	--	--	--	160	--	--	--	130
01S42E05ADBB01	02-27-76 06-02-76	--	-- <100	-- --	-- <1	-- <10	-- 220	-- --	-- <60	-- <20	30 50

Lead (Pb)	Lithium (Li)	Manganese (Mn)	Mercury (Hg)	Nickel (Ni)	Selenium (Se)	Silver (Ag)	Strontium (Sr)	Tin (Sn)	Zinc (Zn)	Source of data
<40	10	<10	--	--	<1	--	--	--	--	BM
50	60	10	--	<10	<1	10	5,500	--	<10	BM
<50	20	<10	--	--	<1	--	--	--	--	BM
<40	80	<10	--	20	<1	20	6,000	--	<10	BM
130	60	260	--	90	<2	<10	12,200	400	90	BM
<40	60	210	--	--	<1	--	--	--	--	
100	60	1,200	--	--	--	--	--	--	--	BM
<40	90	<10	--	--	--	--	--	--	--	
<50	--	1,600	--	--	--	--	--	--	--	BM
110	70	1,700	--	--	--	--	--	--	--	
--	70	670	--	30	<1	10	8,600	--	<10	
<10	70	500	--	--	--	--	--	--	--	BM
100	70	550	--	--	--	--	--	--	--	
270	900	760	<.5	120	<1	50	12,400	<100	30	
<10	90	650	.5	80	<2	10	11,800	810	50	BM
90	70	710	--	--	--	--	--	--	--	
50	80	840	--	50	<1	40	3,300	<10	<10	
100	120	1,400	--	--	--	--	--	--	--	BM
90	70	540	<.5	120	<2	10	13,200	1,400	320	BM
<10	80	610	<.5	130	<2	10	11,800	880	50	
<10	80	920	--	150	<2	10	10,500	720	380	
90	70	1,000	--	--	--	--	--	--	--	
<40	30	<10	--	--	--	--	--	--	--	
<40	60	770	.5	60	<1	20	7,700	<10	20	
120	60	<10	--	<10	<1	30	5,600	--	<10	BM
<40	50	470	--	20	<1	<10	1,300	--	<10	BM
60	60	690	--	40	<1	10	13,500	--	40	BM
120	90	1,100	--	--	--	--	--	--	--	BM
40	80	1,100	--	--	<1	--	--	--	--	
<40	20	<10	--	--	--	--	--	--	--	BM
--	--	140	--	--	--	--	--	--	--	GS
--	40	180	--	--	<1	--	4,500	--	--	
--	30	20	--	--	<1	--	980	--	--	GS
--	30	20	--	--	--	--	--	--	--	GS
<60	30	80	--	<60	1	--	3,400	<60	30	

Table 11.--Representative saturation indices from WATEQF for water from coal aquifers in the Big Sky Mine study area

Mineral	Saturation index for indicated well number and date of collection				
	01N41E16BABA02 (5-18-75)	01N41E21DBDB01 (8-10-81)	01N41E27DCCA01 (6-05-81)	01N41E27CAAC01 (6-05-80)	01N41E27BADC05 (6-05-80)
Quartz (SiO ₂)	0.56	0.70	0.71	0.62	0.65
Calcite (CaCO ₃)	.51	.21	.48	.53	.58
Aragonite (CaCO ₃)	.22	-.08	.18	.24	.29
Dolomite [CaMg(CO ₃) ₂]	1.17	.68	1.24	1.36	1.39
Magnesite (MgCO ₃)	.35	.17	.46	.54	.51
Albite (NaAlSi ₃ O ₈)	---	---	.67	.62	.66
Gypsum (CaSO ₄ ·2H ₂ O)	-1.14	-.15	-.01	-.01	-.15
Anhydrite (CaSO ₄)	-1.47	-.47	-.36	-.36	-.49

Table 12.--Representative saturation indices from WATEQF for water
from the Big Sky Mine spoils

Mineral	Saturation index for indicated well number and date of collection				
	01N41E22CCAD01 (8-12-81)	01N41E27ACCC01 (6-05-80)	01N41E27ADCC01 (5-29-80)	01N41E27DABB02 (8-15-79)	01N41E27ABCC03 (7-21-77)
Quartz (SiO ₂)	0.45	0.56	0.51	0.65	0.57
Calcite (CaCO ₃)	.10	.24	.58	.96	.29
Aragonite (CaCO ₃)	-.19	-.06	.29	.67	-.01
Dolomite [CaMg(CO ₃) ₂]	.47	.77	1.26	2.21	.98
Magnesite (MgCO ₃)	.07	.24	.37	.95	.39
Albite (NaAlSi ₃ O ₈)	-.53	.62	-.76	---	.43
Gypsum (CaSO ₄ ·2H ₂ O)	.02	-.07	.10	-.16	.18
Anhydrite (CaSO ₄)	-.31	-.44	-.23	-.49	-.17

Table 13.--Common-constituent concentrations in water from batch-mixing experiments using materials from the Big Sky Mine area

[Constituents are dissolved and concentrations are reported in milligrams per liter. Analyses by Montana Bureau of Mines and Geology. Source of water: R, Rosebud coal bed; Sm, spoils in Miller Coulee. Source of mixing material: R, Rosebud coal bed; Mc, McKay coal bed; Sm, spoils in Miller Coulee; Se, spoils in Emile Coulee. Abbreviations: micromhos, micromhos per centimeter at 25° Celsius; °C, degrees Celsius; <, less than]

Sample designation	Date	Source of water	Source of mixing material	Mixing ratio by weight (water: material)	Specific conductance (micromhos)	Onsite pH, units	Temperature (°C)	Calcium (Ca)	Magnesium (Mg)
BS44451*	12-08-81	R	---	---	3,450	7.5	22.5	300	350
B1M211			Sm	2:1	3,820	7.5	22.0	380	370
B1M212				2:1	3,820	7.5	22.0	380	370
B1M511				5:1	3,650	7.6	22.0	320	340
B1M512				5:1	3,650	7.6	22.0	330	360
BS44452*	12-10-81	R	---	---	3,500	7.5	22.0	320	360
B1E211			Se	2:1	5,180	7.4	22.5	430	510
B1E212				2:1	5,180	7.5	22.5	400	490
B1E511				5:1	4,350	7.6	22.5	410	420
B1E512				5:1	4,320	7.5	22.5	380	400
BS46471*	12-29-81	Sm	---	---	4,500	7.7	21.5	400	420
B2R111			R	1:1	4,050	6.5	21.5	340	410
B2R112				1:1	3,800	6.5	21.5	290	380
B2R211				2:1	4,100	6.6	21.0	300	400
B2R212				2:1	4,010	6.6	21.0	330	410
B2R511				5:1	4,250	7.0	21.0	360	410
B2R512				5:1	4,250	6.8	21.5	360	420
BS46472*	01-06-82	Sm	---	---	4,500	7.0	21.0	430	420
B2K111			Mc	1:1	4,150	6.4	21.5	430	370
B2K112				1:1	4,190	6.2	21.5	440	370
B2K211				2:1	4,350	6.6	21.0	450	400
B2K212				2:1	4,350	6.5	21.0	480	400
B2K511				5:1	4,450	6.7	21.0	440	420
B2K512				5:1	4,400	6.8	21.5	500	430

*Control sample.

Sodium (Na)	Potas- sium (K)	Silica (SiO ₂)	Bicar- bonate (HCO ₃)	Carbo- nate (CO ₃)	Sulfate (SO ₄)	Chloride (Cl)	Fluo- ride (F)	Dissolved solids, calculated
120	8	20	870	0	1,700	13	0.2	2,920
120	12	20	740	0	2,100	7.6	.3	3,330
120	12	21	700	0	2,100	8.5	.4	3,320
120	10	20	730	0	1,800	7.8	.2	2,970
120	10	20	720	0	1,900	10	.2	3,060
110	8	20	930	0	1,700	11	.2	2,980
280	18	19	790	0	3,000	35	<.1	4,640
280	18	20	800	0	2,900	37	.1	4,560
180	13	20	710	0	2,400	26	.1	3,820
190	13	25	830	0	2,300	27	.2	3,690
200	17	12	650	0	2,500	42	.3	3,960
150	12	11	320	0	2,500	6.5	4.0	3,570
140	11	11	260	0	2,300	8.1	3.8	3,300
170	13	11	350	0	2,500	17	2.8	3,560
170	13	11	350	0	2,500	16	3.1	3,590
180	14	12	470	0	2,500	20	1.4	3,740
180	14	12	480	0	2,500	21	1.2	3,750
110	15	12	610	0	2,600	17	.3	4,010
150	12	9.5	250	0	2,600	11	2.7	3,740
150	13	9.3	200	0	2,700	9	2.2	3,810
170	14	11	370	0	2,700	16	.4	3,950
150	14	10	300	0	2,800	14	1.2	4,020
170	14	11	380	0	2,700	16	.6	3,990
160	15	11	510	0	2,800	16	.4	4,180

Table 14.--Trace-element concentrations in water from batch-mixing experiments using materials from the Big Sky Mine area

[Concentrations are dissolved and concentrations are reported in micrograms per liter. Analyses by Montana Bureau of Mines and Geology. Source of water: R, Rosebud coal bed; Sm, spoils in Miller Coulee. Source of mixing material: R, Rosebud coal bed; Mc, McKay coal bed; Sm, spoils in Miller Coulee; Se, spoils in Emile Coulee. Symbol: <, less than]

Sample designation	Date	Source of water	Source of mixing material	Mixing ratio by weight (water: material)	Aluminum (Al)	Boron (B)	Cadmium (Cd)	Chromium (Cr)	Copper (Cu)	Iron (Fe)
BS44451*	12-08-81	R	---	---	200	440	14	40	46	20
B1M211			Sm	2:1	200	390	14	40	61	30
B1M212				2:1	300	440	18	40	64	30
B1M511				5:1	200	380	13	30	50	20
B1M512				5:1	200	420	17	40	57	20
BS44452*	12-10-81	R	---	---	300	390	28	50	60	30
B1E211			Se	2:1	300	730	21	40	67	40
B1E212				2:1	200	720	19	40	59	40
B1E511				5:1	400	520	29	50	71	30
B1E512				5:1	200	520	8	30	48	30
BS46471*	12-29-81	Sm	---	---	90	550	2	20	44	20
B2R111			R	1:1	200	850	16	40	42	100
B2R112				1:1	200	850	26	40	42	30
B2R211				2:1	100	750	<2	4	23	10
B2R212				2:1	100	800	<2	10	26	30
B2R511				5:1	200	670	10	30	40	20
B2R512				5:1	100	680	14	20	45	30
BS46472*	01-06-82	Sm	---	---	100	70	6	20	35	20
B2K111			Mc	1:1	100	1,300	7	30	29	170
B2K112				1:1	100	1,400	13	40	35	350
B2K211				2:1	200	1,200	13	40	34	100
B2K212				2:1	300	1,500	27	60	47	40
B2K511				5:1	200	1,200	12	40	37	50
B2K512				5:1	300	80	30	60	55	30

*Control sample.

Lead (Pb)	Lith- ium (Li)	Manga- nese (Mn)	Molyb- denum (Mo)	Nickel (Ni)	Silver (Ag)	Stron- tium (Sr)	Tita- nium (Ti)	Vana- dium (V)	Zinc (Zn)	Zirco- nium (Zr)
50	50	290	80	90	26	4,400	40	45	80	30
80	50	20	240	130	42	4,100	60	60	<10	50
100	60	20	260	110	51	4,100	50	62	10	50
70	50	30	100	90	31	4,000	40	48	<10	30
60	50	40	170	110	42	4,200	50	58	10	50
100	60	290	120	80	53	4,600	50	66	90	60
90	60	8	70	60	44	4,600	60	68	20	50
100	60	6	60	60	40	4,500	50	57	20	40
120	70	10	100	90	57	4,400	60	76	10	70
100	50	8	60	60	30	4,400	40	49	20	30
<40	70	5	40	40	9	10,000	50	36	10	20
100	60	250	170	40	25	6,000	40	52	10	40
<40	50	250	90	20	<2	5,000	30	11	20	<3
<40	50	220	70	<10	<2	6,300	30	17	<10	<3
<40	60	240	90	<10	<2	6,600	50	23	<10	<3
<40	60	170	80	50	17	7,900	60	41	<10	20
<40	70	180	110	60	22	8,000	50	47	10	30
<40	60	20	110	90	10	9,000	40	46	<10	30
<40	60	330	40	60	13	10,000	50	27	10	20
<40	60	360	<20	50	17	10,000	60	43	10	20
90	60	250	<20	10	18	11,000	60	45	20	30
100	60	300	100	70	41	10,000	60	63	20	60
100	60	250	20	70	25	10,000	60	51	20	30
100	70	2	120	110	52	10,000	70	79	40	70